DEPARTMENT OF INFORMATICS
TECHNISCHE UNIVERSITÄT MÜNCHEN

Bachelor’s Thesis in Information Systems

Software-Supported Collaborative Problem Structuring in the Context of Morphological Analysis

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Software-Supported Collaborative Problem Structuring in the Context of Morphological Analysis

Softwareunterstützung für die kollaborative Problemstrukturierung im Rahmen der Morphologischen Analyse

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Declaration

I confirm that this bachelor's thesis is my own work and I have documented all sources and material used.

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Abstract

Morphological Analysis (MA) is a powerful method when solving complex problems. Within the three stages of this method potential solutions are generated (1), systematically evaluated (2) and explored (3). Since not only expertise of the problem domain, but also creativity is required, the method is mostly applied in group work. However, existing software tools support users in consistency calculation and visualization, but were not designed to support collaboration and distributed groups.
This thesis focuses on the process design of the Analysis Stage (1). Objective of the Analysis Stage is the decomposition of the problem creating a morphological matrix. In this thesis, two revised process models for the Analysis Stage of the MA are proposed. Combining collaborative and individual work, these models aim to increase group performance by stimulating potential process gains and preventing identified process losses. The implementation of a prototypical web application enables collaborative work and supports distributed teams. Conducting experiments, the proposed process models and the implemented web application were evaluated.

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1 Introduction

1.1 Motivation

Whether in sports, university or at work, in a lot of daily situations people make use of group work to accomplish tasks or solve problems. Through the combination of individual skills and knowledge increased performance is expected. However, social psychology research (Frey et al., 2011; Jonas et al., 2007) points out, that most groups fail to reach their full potential. The deviation between a group's potential and its actual performance can be seen as a result of process losses and process gains. The occurrence of process losses minimizes the group performance. Whereas process gains may cause an increased performance.

Especially in the field of creative idea generation and complex problem solving, most people think that group work results in more ideas. A popular creativity technique, called Brainstorming, also makes use of group work. Although Brainstorming is a widely used method, it has been proven that people who generate ideas in solitary, are more productive than people using the method of Brainstorming as a group (Diehl et al., 1987). This observation is caused by the occurrence of process losses. To avoid such process losses a number of brainstorming variations were developed. A less known method worth considering in this domain is the Morphological Analysis (MA). This method was developed in the 1960s by Fritz Zwicky and among others refined and extended by Tom Ritchey later on. The Morphological Analysis can be applied to solve complex problems. By decomposing the problem into sub problems and listing sub solutions, this approach provides an overview of all imaginable solution alternatives. But such as in Brainstorming, the process of the Morphological Analysis entails various process losses and gains, which affect the group performance. Consequently groups applying this method mostly fail to reach their group potential. Thus, a new adjusted process model for this method is required.

1.2 Objective and Research Questions

This thesis will focus on the Analysis Stage of the Morphological Analysis. As the first stage of MA it concerns itself with the definition and structuring of the problem. Within this stage the morphological matrix will be created. The purpose of this thesis is to define an extended process model for the Analysis Stage. This process model aims to prevent process losses, so that an increased group performance can be attained. Furthermore a prototypical web application shall be implemented, which supports groups applying the new process model. Moreover the prototypical implementation should allow collaboration and also provide support for distributed teams. The following research questions will be answered within this thesis:

1. Which process losses and process gains affect the group performance in creating a Morphological Matrix?

2. How to design the process of the "Analysis Stage" to minimize process losses and maximize process gains?

3. What are the functional requirements an implementation of the extended process model should meet?

4. Do the experimental findings conform to the defined hypotheses?

1.3 Thesis Structure

Chapter 2 - Related Work

This chapter presents the results of the literature review. Thus, not only the evolution of the Morphological Analysis, but also the application of the method is investigated. Additionally the chapter introduces social psychological theory about the performance of group work. Common process losses and gains are described in this section.

Chapter 3 - Concept

Chapter 4 addresses research question 1 and 2. After identifying relevant process losses and gains of the Analysis Stage, this chapter introduces two variations of an extended process model. Furthermore, functional and non-functional requirements of an application, which supports the proposed process models, are presented in this chapter.

Chapter 4 - Implementation

At first chapter 5 gives an overview about the technologies used for the implementation of the prototype. Then the underlying data model and the system design of the web application is presented. Finally, this chapter illustrates to show the user interface of the implemented prototype.

Chapter 5 - Evaluation

In order to answer the last research question an experiment was conducted. This chapter introduces the setup and results of the experiment. Findings and experimental limitations are discussed in the last section of this chapter.

Chapter 6 - Conclusion

In the conclusion the work of the thesis is summarized as well as future work is proposed.

Related Work

2

> *The morphological method essentially is nothing more than an orderly way of looking at things.*
>
> — **Fritz Zwicky**
> (Professor of Astronomy)

2.1 Evolution of the Morphological Analysis

2.1.1 Morphological Method by Zwicky

The invention of the Morphological Analysis (from greek *morphé*: "study of shape") is ascribed to the swiss astronomer Fritz Zwicky. Zwicky claims, that morphological thinking has been successfully applied by a number of scientists before (Zwicky, 1948, p. 121). However, he was the first who explicitly investigated this field of research and defined applicable methods. One of these methods is the morphological box. The procedure of this method is described in 5 steps (Zwicky, 1966, p. 90):

1. Clear formulation of the problem
2. Definition of parameters
3. Construction of the morphological box
4. Analysis and evaluation of containing solutions
5. Selection and implementation of the best solution

The morphological box, constructed in step 3, contains values for each parameter (dimension, sub problems) of step 2. Thereby, various overall solutions of the original given problem (step 1) emerge by combining these values (sub solutions). Thus, the morphological box can be seen as a multidimensional matrix of solutions. Since it is not possible to implement all solutions, step 4 aims to evaluate all possible configuration according to usefulness and realizability. Previous experiences and existing knowledge provide the basis of assessment (Zwicky, 1966, p. 99). In this way a solution space, as a subset of all theoretical configurations of the

morphological box, can be derived. Finally, the implementation and construction of the most promising solution will be done in step 5.
However, this method is only applicable to smaller problems. Considering that a comparatively small matrix with only five dimensions (A-E), each containing about six values (a-f), already illustrates $6^5 = 7776$ configuration. To review and evaluate all of these solutions would take days or even weeks.

2.1.2 Further Development of Morphological Analysis

In the 1990s, the method of morphological box has been used in various fields of research. The scientists Russell Rhyne solved the problem of the non-adaptability for larger, more extensive problems (Rhyne, 1981, pp. 334-346). As part of the FAR-Method (*field anomaly relaxation*), he utilizes the morphological box for a clear representation of future scenarios. This way, large sized matrices were formed which required a more structured procedure for reducing the set of containing configurations. By means of a consistency matrix, impracticable configurations can be filtered through a pairwise consistency evaluation. That means, that as soon as a combination of two values (e.g. {Ca, Ec}) is identified as not consistent (= not realizable), all configurations containing this pair of values are not realizable either (e.g. {Ab,Bc,Ca,De,Ec} or {Aa,Bc,Ca,De,Ec}). Thus, the number of possible configurations is reduced by 216 (6^3). This shows, that the requirement of the internal consistency is a effective and powerful filter.
Likewise, the process for scenario analysis of Ute Reibnitz (Reibnitz, 1992, pp. 49-53) uses such a consistency matrix to group alternatives. In difference to the FAR-Method, which only assesses value pairs as consistent or inconsistent, Reibnitz proposes a 5-level-scale. In this way, the calculation of consistent configurations gets more complex and cannot be handled manually anymore. This is why the scenario process is supported by a particular software solution (Reibnitz, 1992, pp. 256-262).

Tom Ritchey, a former Research Director for the Institution for Technology Foresight and Assessment at the Swedish National Defence Research Agency (FOI), extended the method of morphological box by adding a cross-consistency-assessment (CCA). To tap the full potential of this method, Ritchey and his team developed a software called MA/Carma (Ritchey, 2006, p. 796). The process, which is supported by the software, includes three major stages: Analysis, Synthesis and Exploration Stage. As it is illustrated in Figure 2.1, an iteration of these steps might be necessary to success (Zec et al., 2015, p. 2).

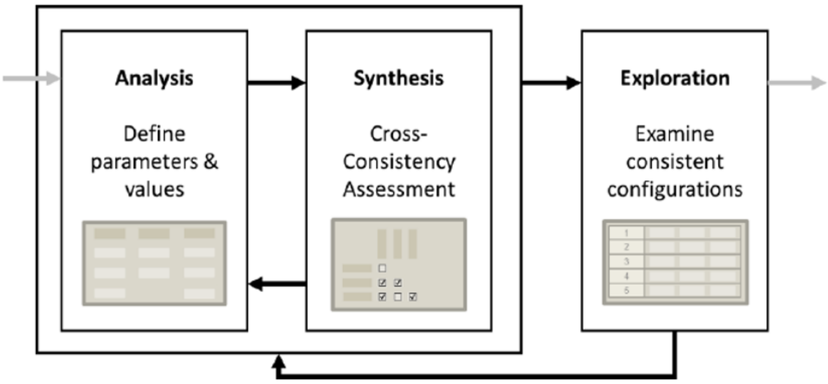
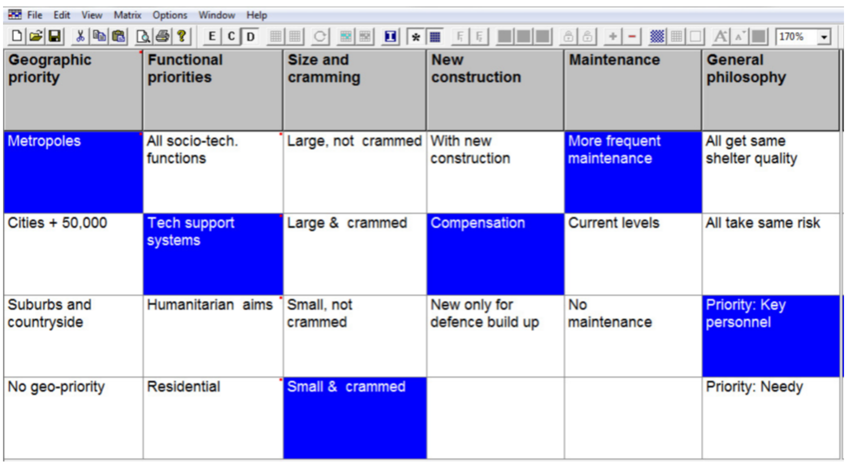


Figure 2.1.: Iterative process model of MA (adopted from Zec et al. (2015, p. 2))

(a) Analysis Stage

The Analysis Stage combines the first three steps of the original five-step process defined by Zwicky. This way, the step aims to define the problem as clear as possible and decompose it through the definition of parameters. Each parameter describes a relevant component of possible solutions. The set of defined parameters should be mutually exclusive and collectively exhaustive (MECE-Rule). While listing possible values for each parameter, a morphological matrix will be created. According to Zec et al. (Zec et al., 2015, p. 2), also implausible or unrealistic values should be added to the matrix. In combination with other values this might lead to creative and innovative solutions. The result of this stage is a morphological matrix, containing all possible configurations and defining a theoretical solution space. Each configuration corresponds to one possible solution of the defined problem. Figure 2.2 presents a morphological matrix, designed using MA/Carma. The configuration of blue highlighted values illustrates one possible solution of the problem.



Geographic priority	Functional priorities	Size and cramming	New construction	Maintenance	General philosophy
Metropoles	All socio-tech. functions	Large, not crammed	With new construction	More frequent maintenance	All get same shelter quality
Cities + 50,000	Tech support systems	Large & crammed	Compensation	Current levels	All take same risk
Suburbs and countryside	Humanitarian aims	Small, not crammed	New only for defence build up	No maintenance	Priority: Key personnel
No geo-priority	Residential	Small & crammed			Priority: Needy

Figure 2.2.: Morphological Matrix – MA/Carma[1]

[1]Source: http://www.swemorph.com/ma.html. Accessed 27. August 2015

(b) Synthesis Stage

Related to the fourth step of Zwickys' approach, the Synthesis Stage deals with the assessment of solutions. Using the criterion of internal consistency, the number of configuration will be reduced. Therefore, a cross-consistency matrix will be constructed (see Figure 2.3). Combining the approaches of Rhyne and Reibnitz, Ritchey (Ritchey, 1998, p. 8) proposes to use different scales depending on the current problem. Using the cross-consistency assessment, a morphological matrix can be reduced by up to 90 or even 99% (Ritchey, 2006, p. 797).

Furthermore, CCA act as a "garbage detector" of vague defined parameters or values. When revealing such ambiguous parameters, a further iteration of the Analysis Stage is required (Ritchey, 1998).

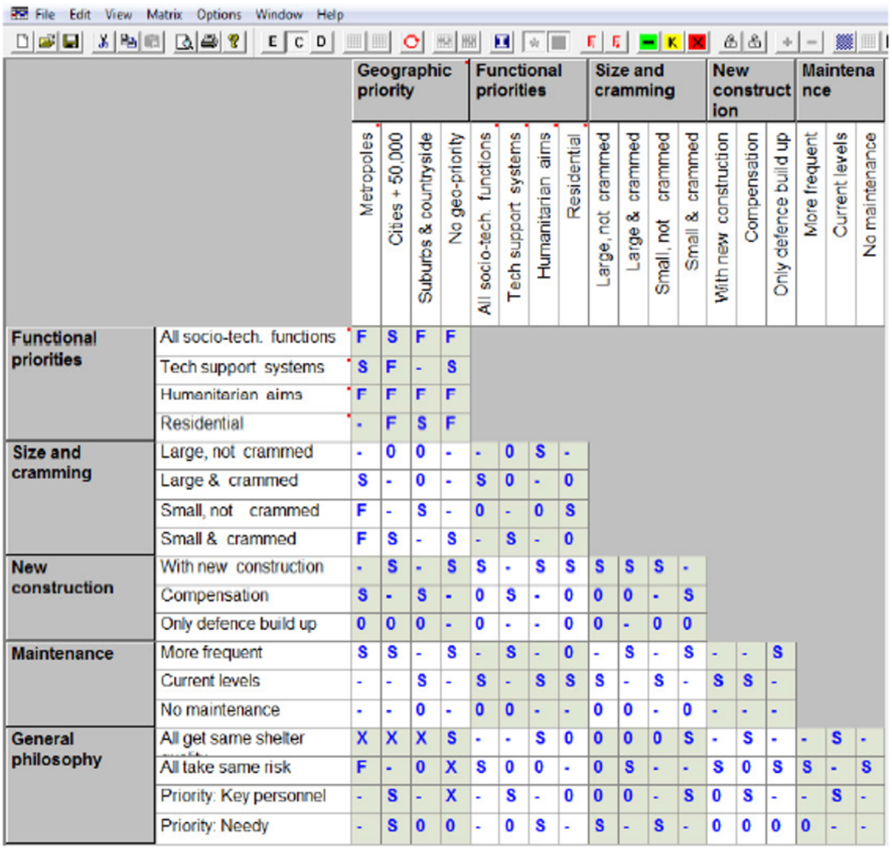


Figure 2.3.: Cross-Consistency Matrix – MA/Carma[2]

(c) Exploration Stage

In the last stage of MA the remaining solutions (configurations fulfilling the criterion of internal consistency) are explored. Instead of simply printing a list of consistent configurations, MA/Carma provides an interactive way of exploring the solution space. Using a *What-if*-Simulation, users can select so-

[2]Source: http://www.swemorph.com/ma.html. Accessed 27. August 2015

called "Input Values" (see red highlighted values in Figure 2.4) and the system displays consistent values of the remaining parameters (blue highlighted). Another software tool, Parmenides Eidos, provides a more graphical visualization of the solution space (see Figure 2.5). Configurations are depicted as circles, its colors and sizes representing the internal consistency. The distances between circles illustrate the similarity of certain configurations.

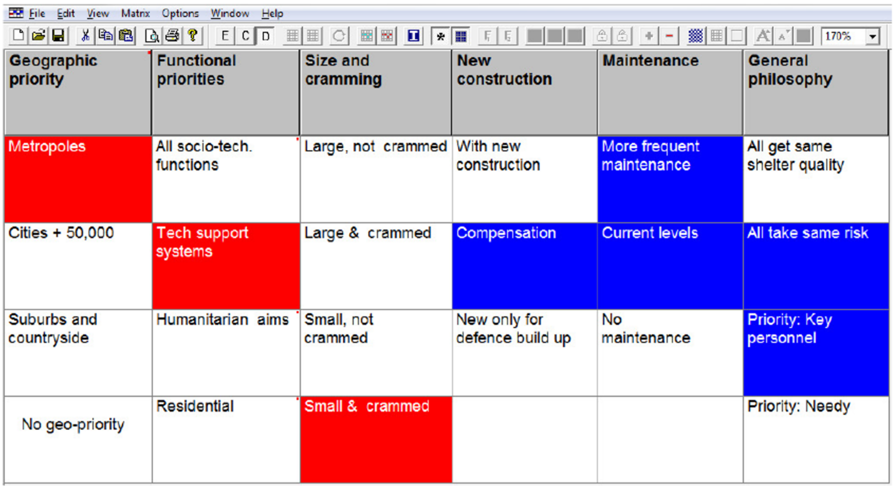


Figure 2.4.: *What-if*-Simulation – MA/Carma[3]

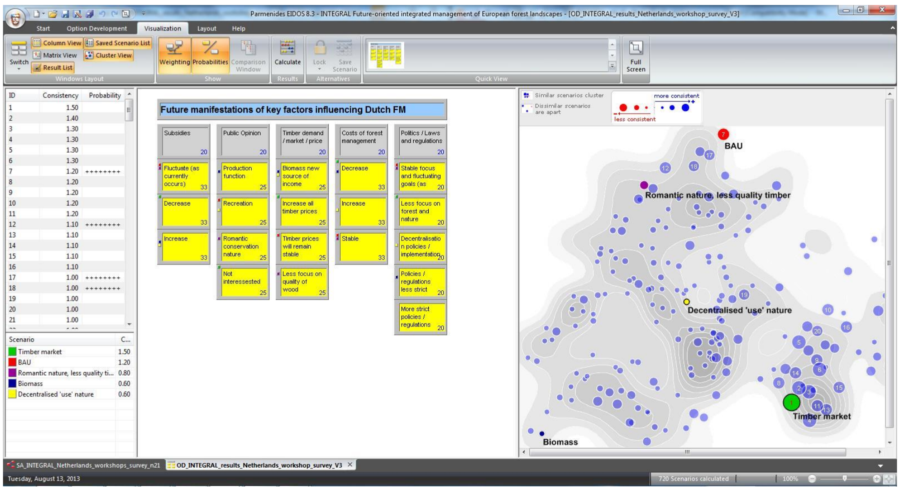


Figure 2.5.: Visualization of configurations – Parmenides EIDOS[4]

The main advantages of available software, like MA/Carma and Parmenides Eidos, are the support in consistency calculation and the visualization of the generated solution space. This allows to also apply MA for bigger problems. However, existing software tools were not designed to support collaborative work (Zec et al., 2015).

[3]Source: http://www.swemorph.com/ma.html. Accessed 27. August 2015

[4]Source: `https://forestwiki.jrc.ec.europa.eu/integral/index.php/South-East_Veluwe` Accessed 27. August 2015

Furthermore, the tools are still very complex, so that an application of the MA always requires an methodical expert moderating the process (Ritchey, 2006).

2.1.3 Application of the Morphological Analysis

Fritz Zwicky, the inventor of this method, mainly applied morphology in the context of his research in the field of astrophysics. The best known example is the application of the morphological field for the development and discovery of new rocket propulsion systems.
According to Ritchey (Ritchey, 2006, p. 796), in the years between 1996–2006 the software MA/Carma has been utilized in more than "50 client-based projects, for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analyzing organizational and stakeholder structures".
The article "Applications of GMA" (Álvarez et al., 2015) outlines in which research areas and for what purposes the method was addressed and applied. Therefore, the following classification was used:

- *Engineering and product design*
- *General design theory and architecture*
- *Futures studies and scenario development*
- *Technology foresight/technological forecasting (broken out of Futures Studies)*
- *Management science, policy analysis and organizational design*
- *Security, safety and defense studies*
- *Creativity, innovation and knowledge management*
- *Modeling theory, OR methods and GMA itself*

Furthermore, it turned out that the morphological analysis can be very helpful when designing new process models (Im et al., 2013; Seidenstricker et al., 2014).
In general, the MA is used to solve complex problems (*wicked problems*). This type of problem cannot be solved by using any linear algorithm. In contrast to *tame/benign* problems, complex problems usually cannot be clearly formulated. Furthermore, solutions of complex problems cannot be identified as "right" or "wrong", solutions can only be ranked as better or worse (Rittel et al., 1973).
In the literature of innovation and product management, the morphological box is introduced as a creativity tool (Gassmann et al. 2011, Pepels 2013). Additionally,

this method is mentioned on several websites and private blogs[5]. Most of the time, the description of the method refers to the 5 step process described by Zwicky. That means, a morphological matrix will be constructed and heuristically evaluated.
As this approach does not contain any consistency calculation, most of the time a procedure using paper-and-pen or a whiteboard is proposed. The method is only recommended to people having know how of the problem domain. In addition, experience with the application of creativity techniques is a prerequisite of a successful performance. Malorny et al. (Malorny et al., 1997) and Schmitt et al. (Schmitt et al., 2010) claim that also a skilled facilitator is required.
The recommended group size varies between 1-4 (Malorny et al., 1997) and a maximum of 10 people (Pepels, 2013). Time needed for this method depends on the size and complexity of the problem. Consequently, different information about the time can be found in the literature. According to Gassmann et al. (Gassmann et al., 2011, p. 308), the morphological method can be completed in about 2 hours. Whereas the innovation coach Benno von Aerssen[6] mentions a duration of several days or weeks.

2.2 Group Tasks and Group Performance

According to the textbook "Sozialpsychologie - Interaktion und Gruppen" by D. Frey and H. Bierhoff (2011), the following section outlines the theoretical foundation of group tasks and group performance.

Steiner's Taxonomy of Tasks
In order to classify tasks, Steiner (Steiner, 1972) makes use of the correlation between individual performances and group performance. Depending on how individual contributions will be combined, Steiner defines four types of tasks: disjunctive, conjunctive, additive and discretionary. In general, these are "unitary tasks" (Steiner, 1972, p. 16), which means the tasks cannot be divided into sub tasks. Consequently, the task must be processed in collaborative group work.
The group performance of **disjunctive tasks** depends on the performance of the best group member. An example would be decision making. The quality of a decision refers to the quality of the chosen alternative. This way, the group performance corresponds to the performance of the member, which submitted the best alternative. Working on a disjunctive task, the group potential increases as the number of group members grows.
On the contrary, the group performance of **conjunctive tasks** is determined by the least competent member of the group. Supposing that the goal of a task is to attain the summit as a whole group, the group performance equals the performance of the

[5] gruenderlexikon.de, ideenfindung.de
[6] see http://www.ideenfindung.de/morphologischer-kasten.html

slowest group member. Thus, the group potential decreases with increasing group size.
For **additive tasks**, the group performance can be calculated as the sum of individual contributions. Pulling a rope (tug of war) is an example of this type of tasks. While pulling a rope, the group is as strong as the sum of the individuals physical strengths. The group potential in additive tasks grows linear with the group size.
Discretionary tasks are tasks in which groups can combine individual contributions in different ways. For example, in forecasting not all individual opinions are weighted equally. Opinions of experts will influence the resulting forecast more than other opinions. This way, the group performance strongly depends on how group members judge the individual opinions. There is no general definition of the group performance of discretionary tasks, but one approach is to define the group potential as the average value of the individual performances.

Actual Group Performance
The calculated group performance (=group potential) does not always align with the achieved group performance. During group work, group performance is affected by social interdependence and social interactions. Hackman et al. (Hackman et al., 1975) defined the following formula to calculate the group performance:

Actual group performance = group potential - process losses + process gains.

In case of dominating process losses, group performance falls below group potential, whereas process gains can cause the actual group performance exceeding group potential.

2.2.1 Process Losses and Process Gains

Group processes can influence the motivation, the individual capability and the coordination of individual contributions. Thus, process losses and gains can be classified as "motivation", "individual capability" or "coordination" losses and gains.

	Process Losses	**Process Gains**
Motivation	Social Loafing Free Riding Sucker Effect	Köhler Effect Social Competition Social Compensation
Individual Capability	Cognitive Restriction	Cognitive Stimulation
Coordination	Ringelmann Effect Production Blocking	

Table 2.1.: Classification of Process Losses and Gains (adopted from (Frey et al., 2011, p. 233))

Motivation Losses and Gains

As mentioned before, the process of a task can influence the motivation of individual group members and in this way also the group performance.
If the individual contribution of a member is not identifiable, group members may reduce their effort and performance (**social loafing**) (Latané et al., 1979).**Free riding** occur in the case that group members reduce their effort because of their perception that tier contribution only have little impact on the group performance (Kerr et al., 1983). Consequently, other group members may reduce their effort to avoid being exploited (**sucker effect**) (Kerr, 1983).
However, the individual performance can also lead to an increase in motivation. Particularly in conjunctive tasks the **Köhler effect** *(indispensability effect)* occurs (Hertel et al., 2000). This effect describes the phenomena, that the least competent member raises its effort in oder to avoid being responsible for a poor group performance. In the case of balanced individual capabilities, **social competition** may raise the motivation and performance of the group members. Especially if individual contributions are identifiable, social competition occurs (Stroebe et al., 1996). The phenomena that high performing individuals may increase their effort to equate the weak performance of other group members is called **social compensation** (Williams et al., 1991).

Individual Capability Losses and Gains

Working in a group does not only influence the motivation of individuals, but also the capabilities.
Especially in additive tasks like Brainstorming, **cognitive restrictions** occur. The ideas of other group members may set a "line of thought" and this way the number of generated ideas decreases.
On the contrary, the ideas of other group members may also act as an inspiration for more ideas. So **cognitive stimulation** can be named as an individual capability gain.

Coordination Losses and Gains

In order to reach a group performance, a combination and coordination of individual contributions is necessary. Coordination losses occur, when the groups fail to coordinate the individual contributions in the best way.
This phenomena has emerged in the experiments of Ringelmann (Ringelmann, 1913) for the first time. He investigated the individual performance of people pulling a rope in solitary or as part of a group (**Ringelmann effect**). The experiments showed, that the average weight pulled by individuals decreases in the same way the group sizes increases. Besides motivation losses, Ingham et al. (Ingham et al., 1974) considered coordination losses to be reason for the decreased average performance.
Production blocking is another coordination loss occurring in additive tasks. Conducting Brainstorming experiments, Diehl et al. (Diehl et al., 1991) found that participants working in a group generate less ideas since their thinking is interrupted by other team members expressing other ideas.
In fact, coordination losses were mainly investigated in the context of additive tasks. But it is also conceivable that the group performance of disjunctive or discretionary tasks is influenced by coordination losses. For example in decision making: if the group fail to identify the best alternative, the actual group performance is below group potential.
Coordination gains were actually discussed by some authors, but neither defined nor empirically tested.

Further Process Losses and Gains

In addition to the process losses and gains explained above, Nunamaker et al. (Nunamaker et al., 1991) mentioned the following phenomena, which should be considered when designing group software.

- **Attenuation, Concentration & Attention Blocking** These are sub elements of the production blocking process loss. Attenuation blocking refers to the process loss that occurs when members forget or suppress their ideas since they seem to be less relevant. Concentration blocking occurs when people concentrate on remembering previous contributions instead of generating new ideas. It is called attention blocking, when group members do not have time to think about the problem, because they are constantly listening to other group members.

- **Conformance Pressure & Evaluation Apprehension** Conformance pressure occurs when members avoid to criticize contributions of other members because of politeness or fear of reprisals. Whereas evaluation apprehension describes the fear of negative evaluation which causes group members to retain their ideas and arguments.

- **Coordination Problems** Coordination problems are described as the lack of having an appropriate strategy, which results in cycling and incomplete discussions. In the context of decision making this might lead to a phenomena called *hidden profiles* (Frey et al., 2011, p. 236). Identifying the best solution in hidden profile tasks requires to share and combine individual knowledge of all group members. Therefore, an appropriate discussion and information sharing strategy is needed.

- **Domination** Dominating group members might influence group discussions and decisions in an unproductive manner (Bonner et al., 2007).

- **Information Overload** In a group a high number of information is shared. Information overload refers to the difficulty of evaluating and integrating all information available.

- **Socializing** Communication which is not related to the current task inhibits the group from accomplishing the task successfully.

Apart from the process losses, the following process gains should be facilitated through the software design.

- **More Information** Certainly the group benefits from the fact that it has more information than its members individually have.

- **Synergy** Synergy occurs when group performance increases through the combination of individual skills and knowledge.

- **More Objective Evaluation and Learning** Interactive error detection and correction as well as exchanging each others' solution strategies conduce to enhanced individual capabilities in groups. These process gains can be classified as coordination gains.

2.2.2 Group Performance Management

According to Schulz-Hardt et al. (Schulz-Hardt et al., 2007), group performance management is the sum of activities, aiming to maximize the group-specific component of group performance. In order to improve group performance, the group performance management focuses on three aspects: group composition, group learning and group synchronization.

The composition of the group should be adjusted to the type of task. Moreover, the context of the group work should enable and enhance group learning, so that a increased performance can be achieved in further iterations of the task.

Furthermore, group synchronization aims to prevent the occurrence of process losses and benefit from process gains. Techniques and tools of group synchronization support the collaborative generation, modification and integration of individual contributions in the context of group work (Jonas et al., 2007, p.463). Depending on the current type of task, the following techniques can be utilized to maximize the group performance:

- continuous visibility of individual contributions,
- salience of the importance of own contributions for the group performance,
- communication of performance standards,
- targeted structuring of procedures.

Some of these tools will be used within the process enhancement in chapter 3.

3 Concept

As mentioned in chapter 2, group performance is affected by process losses and process gains. Different variations of Brainstorming, such as Brainwriting or the Nominal-Group-Technique, reveal that changing the process of a method can help to prevent process losses. Also, using software support can prevent process losses and enhance process gains (see Electronic Brainstorming).
With regards to those achievements this chapter identifies relevant process losses and gains of the Analysis Stage of the MA (3.1.1). The new process models will be proposed in section 3.1.2. In order to develop software which supports the proposed process models, sections 3.2 and 3.3 will introduce functional and non-functional requirements.

3.1 Modification of the Analysis Stage Process

3.1.1 Relevant Process Losses and Process Gains

MA is often used in the context of innovation. Not only is subject matter expertise required, but also is creativity essential to find possible parameters and values.
The process of Analysis Stage can be divided into two main processes – divergent thinking and convergent thinking. Divergent thinking is used to freely generate as much ideas as possible, whereas convergent thinking focuses on selecting the best solutions from those ideas (Guilford, 1956).

In the context of MA, divergent thinking describes the process of collecting parameters and values of the problem. This is similar to the process of the group creativity method Brainstorming. Although Brainstorming is a very popular method, group performance suffers process losses. This is evidenced by the fact, that a group produces less ideas while brainstorming together, than would members when brainstorming in solitary. Whilst motivation losses (*free riding, social loafing*) in particular cause this phenomenon, also *production blocking* and *cognitive restrictions* are mentioned as reasons for lower productivity (Diehl et al., 1987). As the divergent process of Analysis Stage is very similar to the Brainstorming it can be assumed, that those process losses also affect the group performance of this stage.
Compared to Brainstorming, the Morphological Analysis is a more complex and structured creativity method. In a morphological matrix especially the parameters

must obey certain rules (e.g. MECE-Rule). So apart from divergent thinking, convergent thinking is required to analyze and filter the gathered ideas by relevance and consistency. For most groups this might be a challenge and cause discussions. During these discussions coordination losses in form of misdirected arguments are possible. The selection of parameters depends on individual opinions. Those might not be weighted optimally, due to social *domination* of individuals or hierarchical composition of the group.
Both, the performance of divergent and the performance of convergent thinking, can be affected negatively by *evaluation apprehension*. This means, that group members won't share all ideas or opinions for fear of being criticized.

However, there are also some process gains, which may positively influence the group performance. *Cognitive stimulation* might help to generate more ideas, also *social competition* may spur groups to higher productivity.

3.1.2 Proposed Process Models

In this section two enhanced process models for the Analysis Stage will be proposed: a basic (3 steps) and an extended (5 steps) process.
Both are based on the extended process model of Zec et al. (2015), who propose a subdivision into individual and collaborative steps to improve information sharing among groups. Regarding the Analysis Stage, this means that group members will first work on the problem and a possible morphological matrix in solitary, before agreeing on a shared matrix.
The proposed processes combine divergent and convergent thinking as well as individual and collaborative work.

Basic process (3 steps)

1. The first step focuses on divergent thinking with the objective to gather ideas for possible parameters and values of the Morphological Matrix. In order to avoid production blocking and cognitive restrictions step 1 is conducted in solitary.

2. In the second step, users are allowed to look through the ideas of other members for the first time. This should enhance cognitive stimulation, which makes them to produce additional values and parameters. To reduce the effect of evaluation apprehension, members are not able to see the creator of parameters or values.

3. This last step addresses convergent thinking. Since the combination of the individual matrices might cause consistency conflicts and overlapping issues, the shared matrix need to be refined in this step.

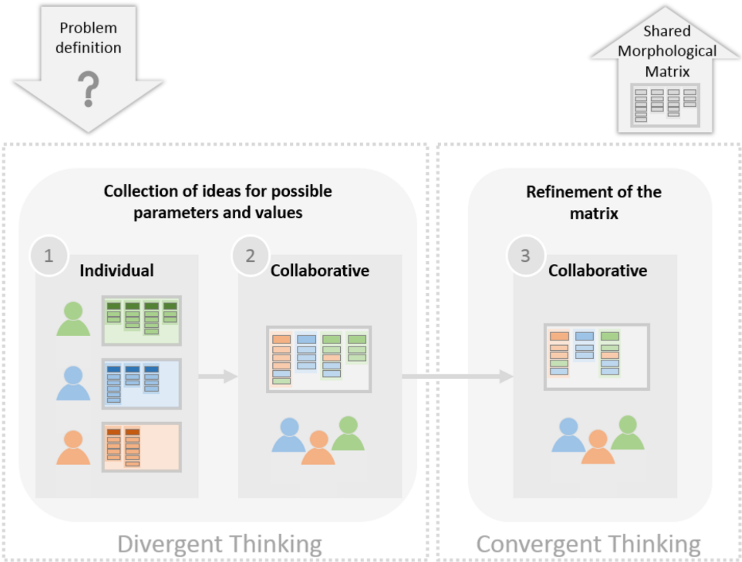


Figure 3.1.: Proposed process model for the Analysis Stage, basic version

Extended process (5 steps)
As mentioned above, the refinement of the shared matrix is a very complex task and will be affected by various process losses. In order to prevent those process losses, and to support group decision making, this task is decomposed in the extended process model. Step 3 and 4 address the selection of parameters. In step 5 the values of the matrix will be revised.

1. This step is similar to the first step of the basic process.

2. The main task of this step equals the task of step 2 in the basic process: adding more values and parameters through cognitive stimulation. However, during the implementation of this process model it became evident, that the second step also requires a convergent thinking task: identification and elimination of duplicated parameters. This will prevent unnecessary duplicate ratings in step 3.

3. In this step group members will evaluate the parameters individually. This results in individual sets of relevant, consistent and non-overlapping parameters. This "individual voting step" is added to the process to avoid social loafing and solve the issues of hidden profile, common knowledge effect and social domination.

4. Using the individual ratings of step 3, the group decides on the "final" parameters collaboratively in this step. In order to create a consistent and non-overlapping set of parameters, the group may add, merge and remove parameters of the matrix. To avoid evaluation apprehension in this step, the individual rating reasons of step 3 are shown anonymously.

5. The last step of the Analysis Stage deals with the values of the matrix. Just as the parameters, values must satisfy some criteria (e.g. MECE, relevance). Especially the values of previously merged parameters require some revision.

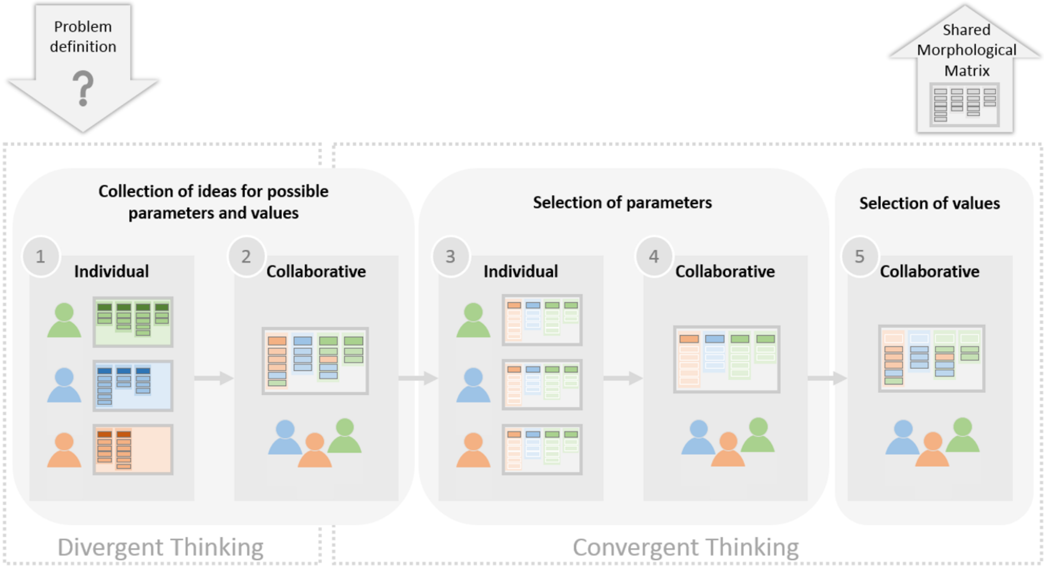


Figure 3.2.: Proposed process model for the Analysis Stage, extended version

3.1.3 Hypotheses

Using the proposed extended process model, the group performance of the Analysis Stage is less affected by...

1. ...motivation losses like social loafing and free riding.

2. ...production blocking and cognitive restrictions.

3. ...the issue of hidden profiles.

3.2 Functional Requirements

An appropriate software support for the proposed process models should perform the following requirements:

Project management
When logged in, an overview of the users' projects should be shown. Moreover, users should be able to create a new project, which contains a short problem title, a more detailed problem description, as well as selected group members. Therefore, the implementation of user accounts is needed.

Basic functionalities

To construct a Morphological Matrix the software must provide input forms to add values and parameters. Based on the current process step, users should also be able to rename, merge and delete parameters and values. Furthermore, step 3 of the basic process and step 5 should provide an undo functionality for deleted parameters and values. In order to prevent manipulation in step 2, user should only be able to edit own contributions.

Layout

A clear visual representation of the matrix is required.

Support for distributed teams

As group members may not be in the same room during the process, supporting software should offer possibilities to communicate. A comment feature can be used to ask questions about the meaning or relevance of a certain parameter. In order to prevent questions it should be possible to add descriptions to the parameters.

Support for consensus building

To decide about parameters in step 3 and 4, a simple up/down rating system should be provided by the software.

For every rating, both the individual ratings in step 3 and the group ratings in step 4, reasons must be given. Therefore, the system should offer some textual input fields. In addition, "down"-rating in step 3 should be simplified by the following rating flags: "Same as" and "Conflict with". When using these rating flags, selected parameters replace the rating reason.

After rating the parameters individually in step 3, the system should present the group ratings, which are calculated according to the individual ratings. Additionally, an overview of the individual rating reasons should be shown.

Process control

Since the process is very complex and the containing steps are built upon each other, a specific process control is required. The software should make sure, that first of all, members can only continue with the next step, if all prerequisites are fulfilled (see Table A.2 in Appendix A). Secondly, the software should ensure that users wait for other group members before starting with a new step. Group members, who already finished the collaborative steps 4 and 5, should be notified about further changes. At this point they are obliged to return to this step, in order to review and approve these changes. In any other case, it should not be possible to return to a completed step.

Anonymity

To evaluate parameters and values more objectively, users should not see the creators' name of parameters/values. For comments and individual ratings, the system should use colors to indicate the author of the contributions without showing names.

3.3 Non-Functional Requirements

In addition to the functional requirements the prototype should comply with the following non-functional requirements:

Usability
During the process, users should always be aware of their current progress and task. Moreover it should be clear how this task can be accomplished. Therefore, the user interface of the application should be as easy-to-use and intuitive as possible.

Collaboration Support
For collaborative steps of the process, the system should display changes of the shared matrix simultaneously on all clients.

Accessibility
The application should be accessible through web browsers, with improved layout for Mozilla Firefox.

Analyzability
The web application will be used in the experiments. In order to evaluate the group performance, user activities should be logged. As an logged in Admin, it should be possible to monitor these activities in real-time. Furthermore, it should be possible to export all stored data as csv-files.

Language
In order to allow international students to attend the experiment, all information text should be written in English.

4 Implementation

This section will first introduce the technologies used for the implementation of the prototype. The data model and system design of the web application will be described in the sections 4.2 and 4.3. Finally section 4.4 presents the implemented functionalities and user interface.

4.1 Technology

In order to meet the requirements, described in section 3, the following technologies were selected:

Meteor Framework
As real-time collaboration is the most crucial requirement of the prototype, the web application is implemented using the full-stack framework Meteor[1]. The main advantages of Meteor are the live updates as data changes. These are received through the usage of DDP (distributed data protocol). Instead of sending HTML, the server sends data, which is rendered on the client ("Data on the Wire"-Principle). The integrated Blaze library simplifies the programming of live-updating user interfaces. Moreover, the framework is built upon the Node.js framework, so it needs only one language for the client as well as for the server: JavaScript. Furthermore, Meteor provides Account packages, which helps to add user accounts to the application and take care about authentication and identification of users.

MongoDB
MongoDB[2] is an open-source document database for semi-structured data. High performance, high availability and automatic scaling are the key features of MongoDB. Similar to JSON objects, documents of MongoDB use field-value pairs to structure the data. MongoDB is used for the web application, because it is the best supported database by Meteor.

Bootstrap
Bootstrap[3] is an open-source front end framework. Containing CSS classes, components and JavaScript plugins it supports and simplifies the development of responsive

[1] Available at: http://www.meteor.com
[2] Available at: https://www.mongodb.org/
[3] Available at: http://getbootstrap.com/

mobile and web applications. The implemented prototype mainly uses the Grid System of Bootstrap for creating the general page layout. In order to increase readability, text inside the web application is supported, or even replaced, by Glyhphicons provided by Bootstrap. The framework also allows to easily add modals or alerts to the application.

4.2 Data Model

The class diagram in Figure 4.1 illustrates the basic data model of the application. The *project* represents the problem to be solved. It contains a title and a description of the problem. The mode of the project describes, which process model (basic or extended) will be used to create the morphological matrix. A project will be created by a *user*, who also select the group members of the project. To describe a problem, users define several *parameters*, which have a title (text) and a description. Every parameter contains at least two *values*, textual described and also created by a user. In order to communicate, group members can add *comments*. Comments are always related to a parameter. The final solution matrix only contains a selection of parameters, that is why users have to rate parameters. The *user ratings* contain a voting (up/down rating), a abstract reason (e.g."Same as", "Conflict with") and further information about the reason. Similar to user ratings, the text of *group ratings* contains a reason of the group voting.

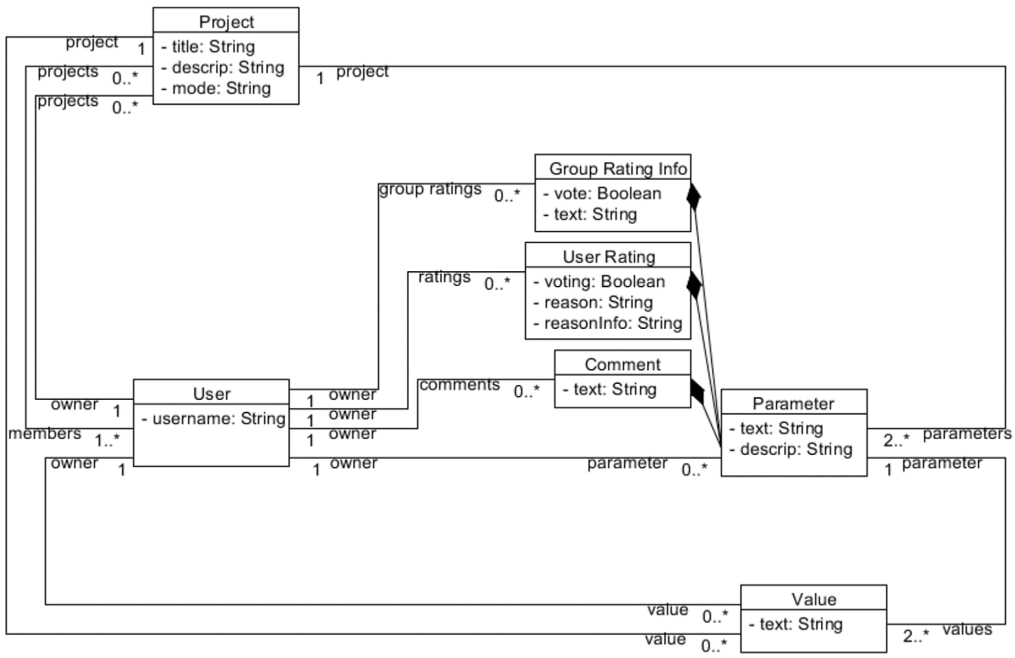


Figure 4.1.: Basic data model as class diagram

4.3 System Design

This section gives an overview of the components of the web application's system architecture.

Collections

As mentioned before, the persistent data is stored using MongoDB. In order to describe the model introduced in section 4.2, the application contains the collections shown in Figure 4.2. In addition to the attributes presented in section 4.2, documents contain several meta information (e.g. *createdAt*, *partOfFinalMatrix*, *valuesChecked*). Meta information is used for process control (e.g. documents of *ProgressList*), as well as for evaluating the group performance (e.g. *LogDataList*). The *RatingList* collection contains the individual parameter ratings, whereas the group ratings are integrated into the *parameter* documents. Instead of removing documents entirely, the *partOfFinalMatrix* field handles the visibility of deleted parameters or values. The *allRead* attribute of *commentsChecked* triggers a "new comment" notification. In step 5 the *valuesChecked* field of a parameter is necessary for process control (see Figure 4.22 in section 4.4.2). In addition to defined attributes, MongoDB automatically adds an unique `_id` field to every inserted document. This `_id` field can be used as a primary key to reference related documents (e.g. `project_id` field in *ProgressList*).

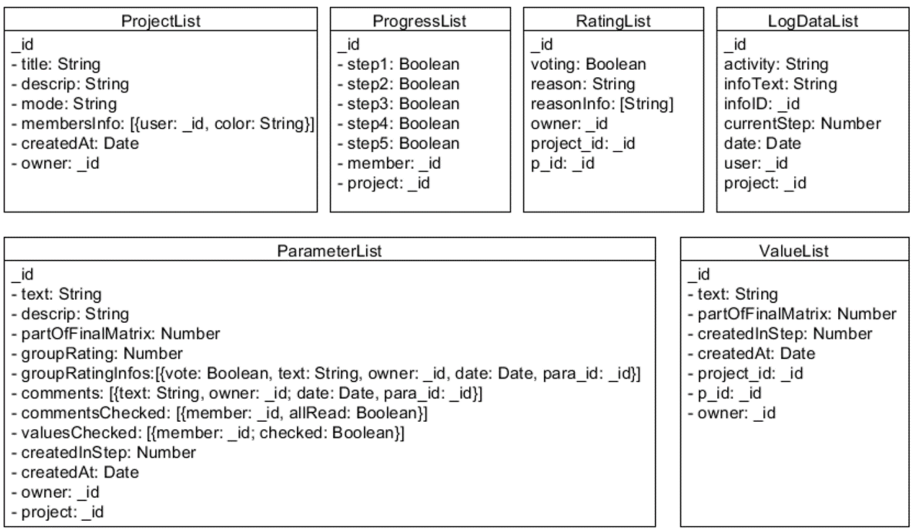


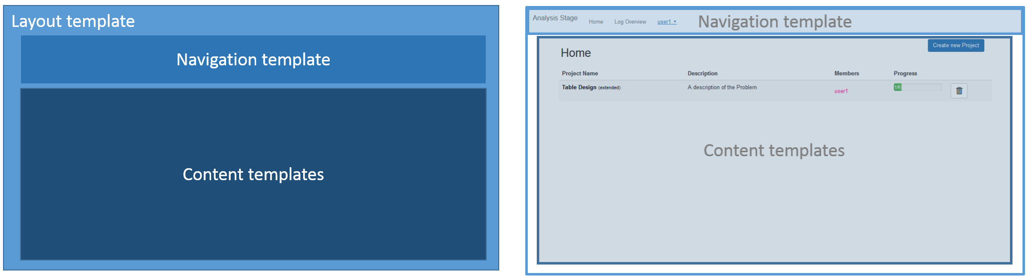
Figure 4.2.: Implemented collection and document structure

Server

A main feature of Meteor is the optimistic UI, realized through the usage of client-side mini mongo databases, which simulate data changes. Even if this improves the user experience - it can be very confusing in the context of group collaboration. In case of connectivity issues group members might see different data, which might impede collaboration. In order to prevent such collaboration problems, the prototype make use of server-side Meteor methods to insert and update documents.

Templates

The Meteor framework uses templates to form the user interface of an application. Besides interface elements, templates also contain application logic to manipulate or reference elements. The Blaze library handles the live-updating, that means views will automatically update, when data changes.
Figure 4.3 shows the general structure of templates building the user interface of the prototype. The layout template includes the navigation template and a template showing the content. Whereas Figure 4.3a is showing a more abstract model, Figure 4.3b uses an edited screenshot of the prototype to illustrate the template structure of the web application.



(a) Abstract scheme of web application

(b) Scheme shown in a screenshot of the prototype

Figure 4.3.: Basic template structure of the application

An overview of all implemented content templates can be seen in Figure 4.4. Opening the web application via *http://collaborativeMA.meteor.com/* users will see the "Home"-template. Logged in as an admin, the administration functionalities are available adding */log* to the URL ("LogOverview"-template). The process folder contains one template for each step of the process model (accessible by adding */[template-name]/[`project_id`]*). Selecting the basic mode for the project, the process contains Step1 to Step3b. The extended process mode makes use of Step1,2,3,4 and 5. Step6 offers an overview of the resulting matrix at the end of both processes. Every "step"-template contains a different individual matrix. The "matrix"-templates mainly uses the same layout, but provided functionalities differ (see Table A.1 in Appendix A - Implementation Details). The "ParaInfoModal"- and "EditModal"-templates are added to almost all process steps. In addition to that, step 3 provides a number of rating modals. The "RatingGraph"-template is included in the" FinalMatrix"-template of step 4, the graph is used to show the result of individual ratings. The "StepProgressGraph"-template is used in "Home"-template, as well as in each "Step"-templates, to display current progress of the process. The red-rimmed templates are implemented but not referenced in the final version of the application. The "Tutorial"-template was used to include a tutorial slides about how to create a morphological matrix in general. The "ProgressGraph"-template was integrated in step 1, to show the users' current contribution status compared to the other group members.

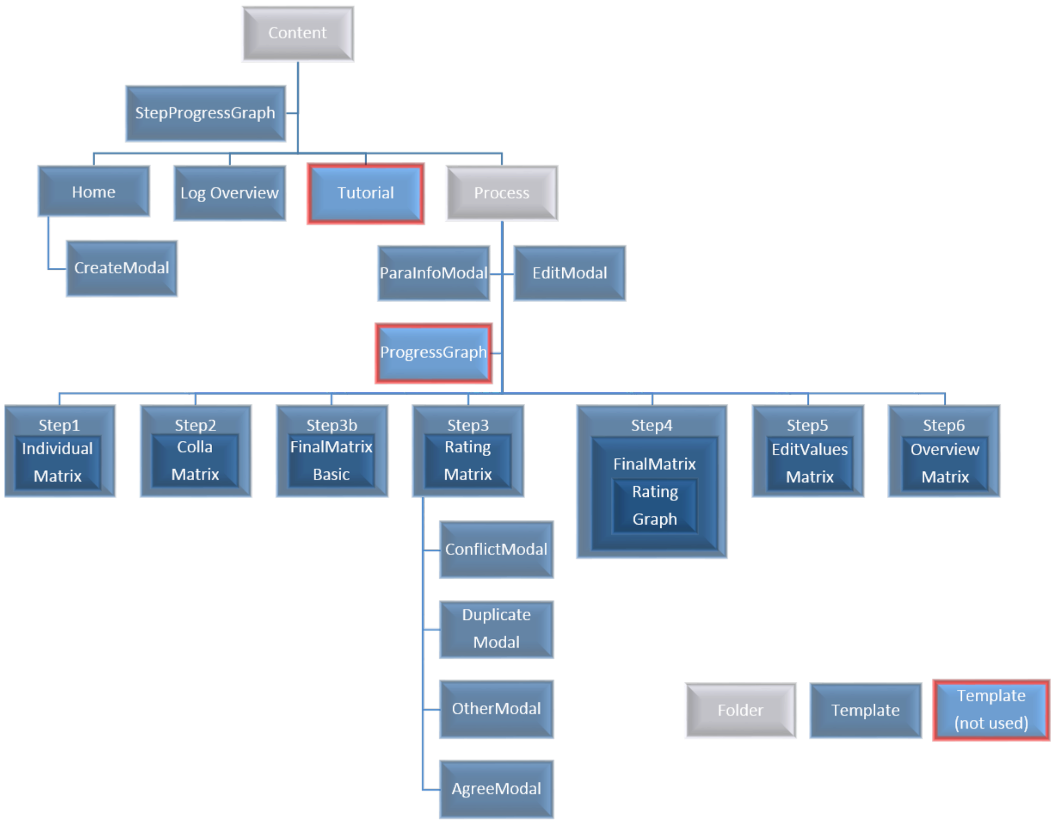


Figure 4.4.: Content templates of application

Public

Static content is stored in the public folder. The folder contains default user images (see Figure 4.7) and images of the process tutorial (see Appendix A - Implementation Details).

Packages

Bootstrap (*twbs:bootstrap*): As mentioned in section 4.1, Bootstrap provides HTML, CSS and JavaScript components for the development of responsive applications.
User Accounts (*accounts-ui and accounts-password*): This packages provide the *loginButtons* template, which is used to add a login widget to the application (see Figure 4.8 in section 4.4.1).
Router (*iron:route*): The Iron Router is a specifically for Meteor designed router, which runs on client and server. It is not only used to define paths for templates, it also allows to pass data between templates.
Export Data (*pfafman:filesaver and harrison:papa-parse*): These packages allow to generate and download files. In order to export the collection data as csv-files, the web application make use of these packages.

4.4 User Interface

The user interface was designed through an iterative process of implementation and evaluation. Identified shortcomes were revised in the next iteration step. Most commonly only small changes (e.g. color or size improvements) has been made. But there still has been some major changes, like the modification of process control. In order to show the evolution of the user interface, this section contains several screenshots of the prototype. Thus, not only the design of the application is presented, but also the implemented functionalities, which enable users to successfully fulfill the tasks of the process.

In order to help the user navigating the application, a set of icons was used (see Figure 4.5). While the icons depicted in Figure 4.5 belong to the Glyphicon[4] Halflings set, the included process tutorial makes use of self-made icons, as well as icons downloaded from UX Repo[5] (see Figure 4.6).

Figure 4.5.: Icon set of the application

[4] Available at: http://glyphicons.com/
[5] Available at: http://uxrepo.com/

Figure 4.6.: Icon set of the tutorial
(from left to right: Windows icon set, Font Awesome icon set, self-made icons)

Besides the usage of icons, the application also contains some default "user images" to represent the creator of comments or ratings. Figure 4.7 shows all available images, whereas the usage of these icons can be seen in Figure 4.16 and 4.20.

Figure 4.7.: "User images" used for comments and individual ratings

4.4.1 User Login and Home Screen

The login form depicted in Figure 4.8 is provided by Meteor. To create a new account only a name and a password is required.

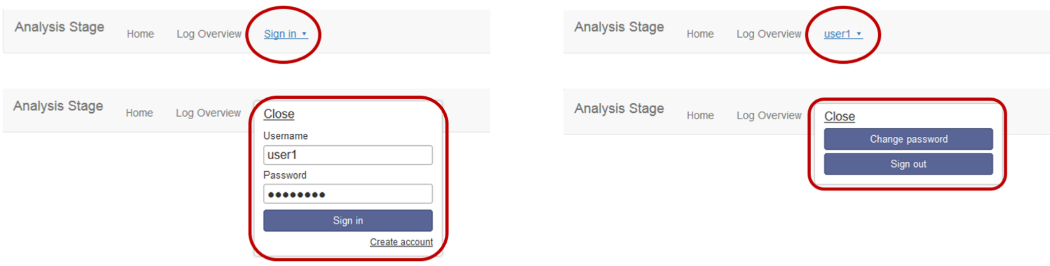


Figure 4.8.: User login & logout form

When logged in, users will see the "Home" screen, showing a list of all projects they are attending (see Figure 4.9). The list contains project name, project description, a list of group members and the user's current progress. The color used for the username inside the members column, indicates in which color comments and ratings of the user will be marked. In order to keep it more anonymously only the own color will be shown, other names remain gray. The modal shown in Figure 4.10 will appear by clicking on the blue button in the upper right corner. In order to create a new project, all input fields of the form must be filled in and at least one group member must be selected. Furthermore, the creator can choose a project mode (= process model). To open a project, users can click on the project name in the first column of the list.

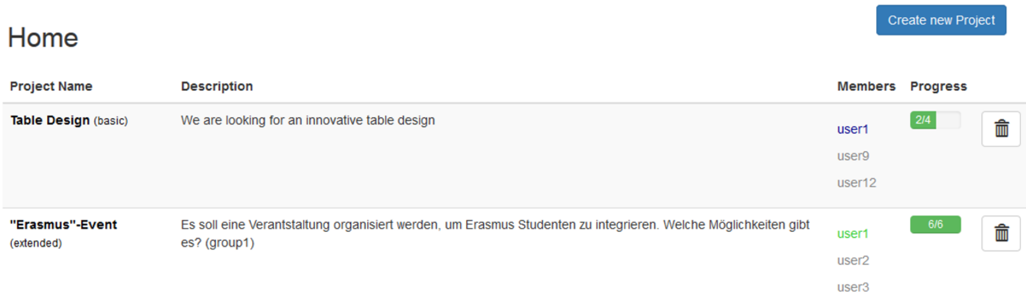


Figure 4.9.: Project table of "Home" screen

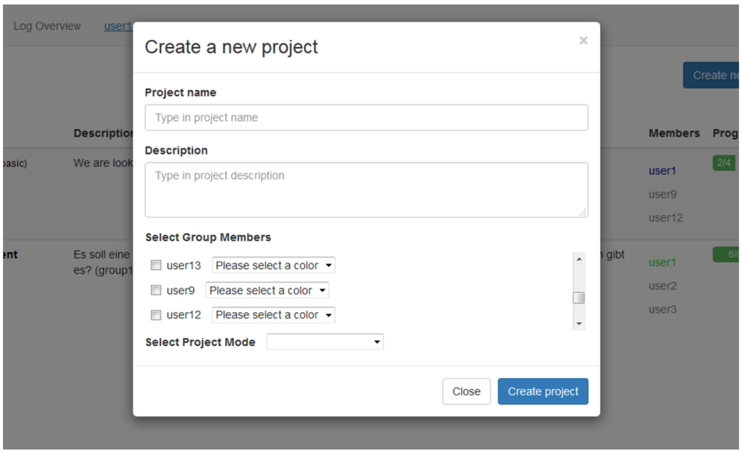


Figure 4.10.: Input form used to create new projects

4.4.2 Process Steps

Step 1

In the first step of the process, users are able to generate ideas for possible parameters and values in solitary. For this purpose only their own contributions are shown in the matrix of step 1. During the development of the prototype, the basic layout of this matrix has been changed. Whereas Figure 4.11 shows an older version of the matrix layout, Figure 4.12 illustrates the latest version. The major improvements are new colors, as well as an rearrangement of the parameter boxes.

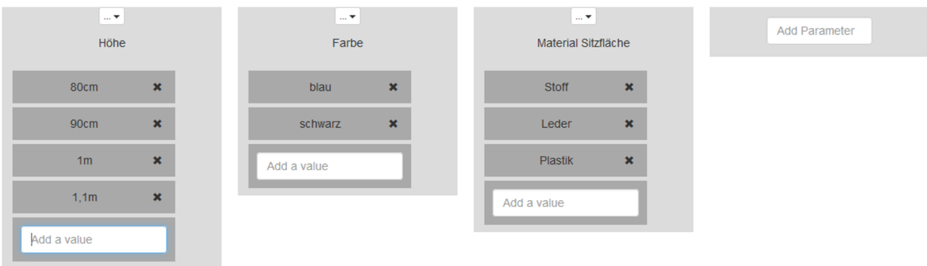


Figure 4.11.: Intermediate status of matrix layout (5. October 2015)

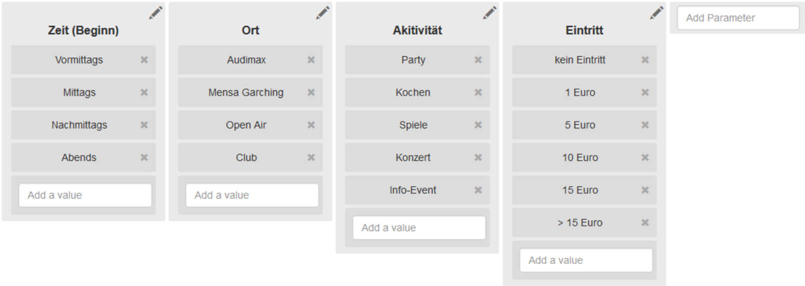


Figure 4.12.: Latest version of matrix layout

Figure 4.13 illustrates how users can edit their matrix. By double clicking a parameter or value field a input form will be shown. This way, users can rename values or parameters. The drop down menu on the right side of the last parameter can be opened by clicking on the pencil icon next to it. Doing this, it is possible to either delete the parameter or open a "Edit Modal". The "Edit Modal" contains input fields for renaming the parameter or adding a description to the parameter. In order to delete a value, the user can click on the cross icon next to the value name.

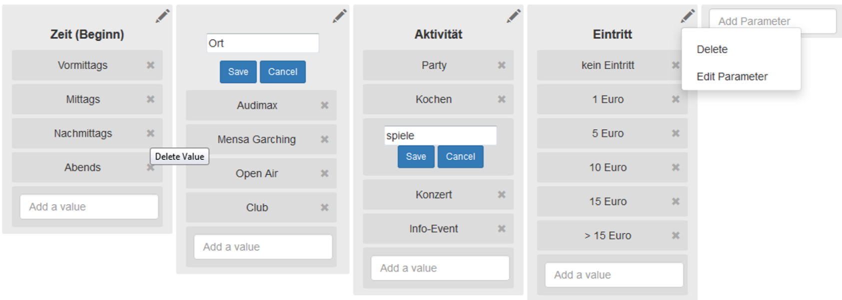


Figure 4.13.: Provided functionalities to edit a matrix

Figure 4.14 shows a snippet of a prior version of the application. This version also contained the "ProgressGraph" template, displaying the productivity of all user. The width (in percentage) of the user's progress bar w_i was defined as follows:

$$w_i = \frac{(n_{p_i} + \frac{n_{v_i}}{2}) * 100\%}{(n_p + \frac{n_v}{2})}$$

where n_p/n_v is the total number of all parameters/values and n_{p_i}/n_{v_i} the number of parameters/values added by user i. It was implemented to stimulate a social competition, but it was removed later on, since it turned out to be too distractive.

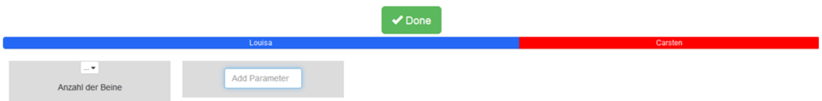


Figure 4.14.: "User Progress Graph" in step 1 (5. October 2015)

Step 2

The matrix shown in the second process step combines parameters and values of all group members. To prevent conflicts, users are only able to edit or delete own parameters or values, but all changes will be visible to all members immediately.
As the shared matrix might contain a number of similar parameters, a drag&drop functionality is provided. Using this feature, values will be moved from one parameter to another (see Figure 4.15).

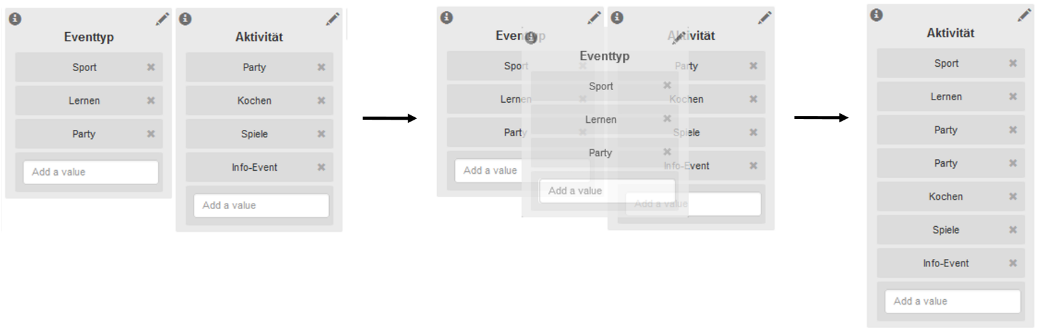
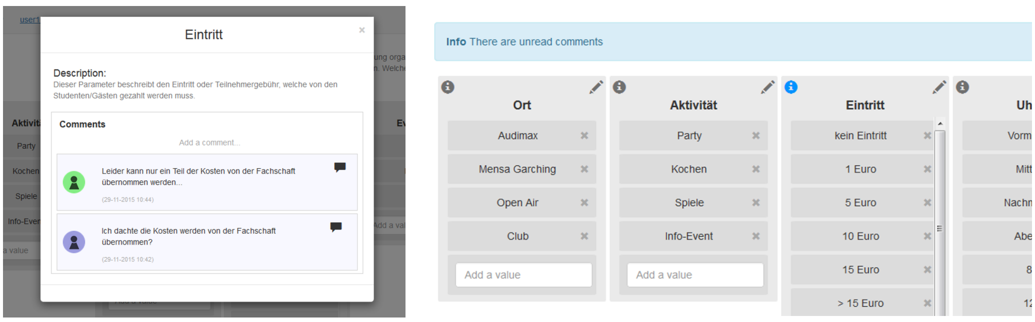


Figure 4.15.: Combining parameters using drag&drop

Since the web application should also support distributed teams, a "comment" functionality was implemented to be used in step 2 - step 5. A comment thread is always related to a parameter and can be opened by clicking on the info icon. Instead of printing the name, colored "user images" were used as an indicator of the comment creator (see Figure 4.16 (a)). Figure 4.16 (b) illustrates, how users will be notified about new comments.



(a) Info Modal **(b)**New unread comments message

Figure 4.16.: Comment feature

Basic process - Step 3

In this last step of the basic process model, users should agree on a shared matrix. In contrast to step 2, users are able to edit and delete own parameters/values as well as parameters and values added by other group members. It is also possible to add parameters or values, but it is not the main objective of this step. This is why users first have to click on "Add value /parameter" before seeing the input field. In difference to the previous steps, the deleting action of this step won't remove the parameters or values, but crosses the name and moves it to the end of the list (see Figure 4.17). This allowed to also add a "undo delete" functionality to this step.

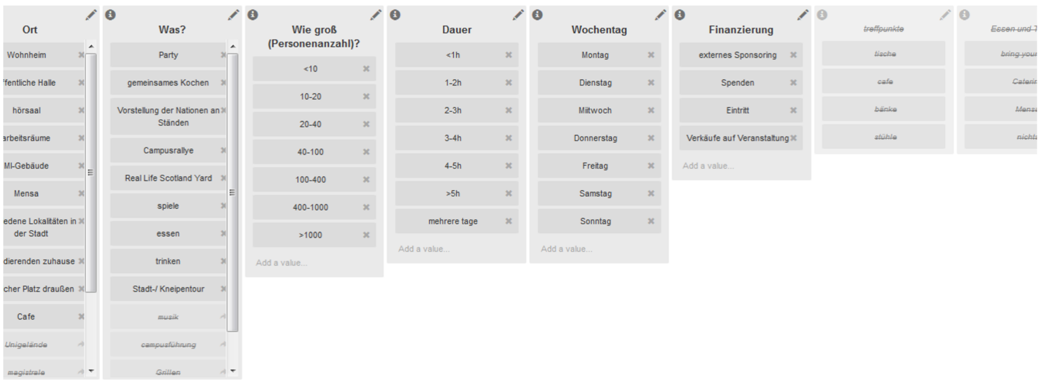


Figure 4.17.: Matrix layout in step 3 (basic)

Extended Process - Step 3

In step 3 of the extended process group members are asked to rate the parameters of the shared matrix in solitary. Each individual rating must be justified. Whereas a positive rating can be reasoned by adding a text. The negative ratings can also be explained by using predefined flags as "Same as" or "Conflict with". In this case the user only has to select affected parameters (see Figure 4.18). Based on the current rating, the parameters are colored green or red in this step (see Figure 4.19). As this step focuses on rating, the users cannot edit or delete any parameters or values.

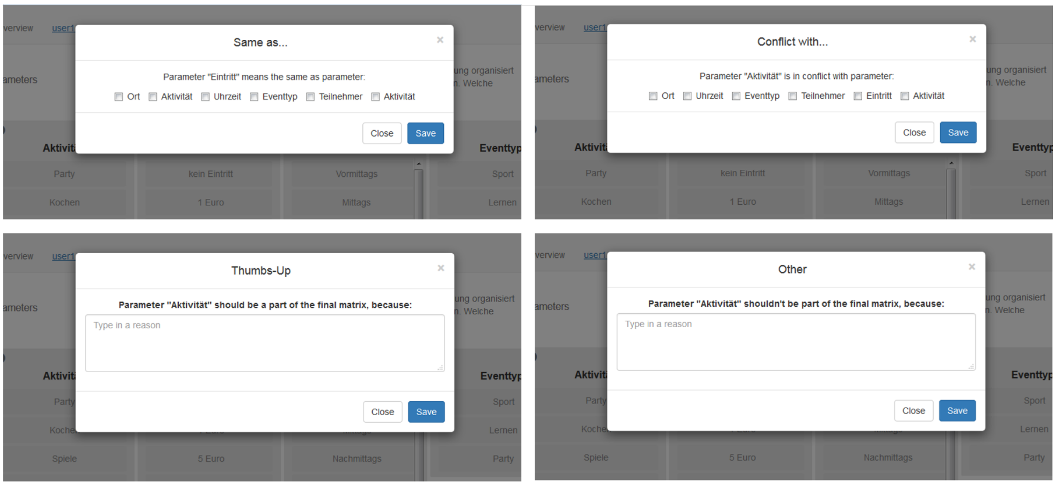


Figure 4.18.: Voting modals in step 3 (extended)

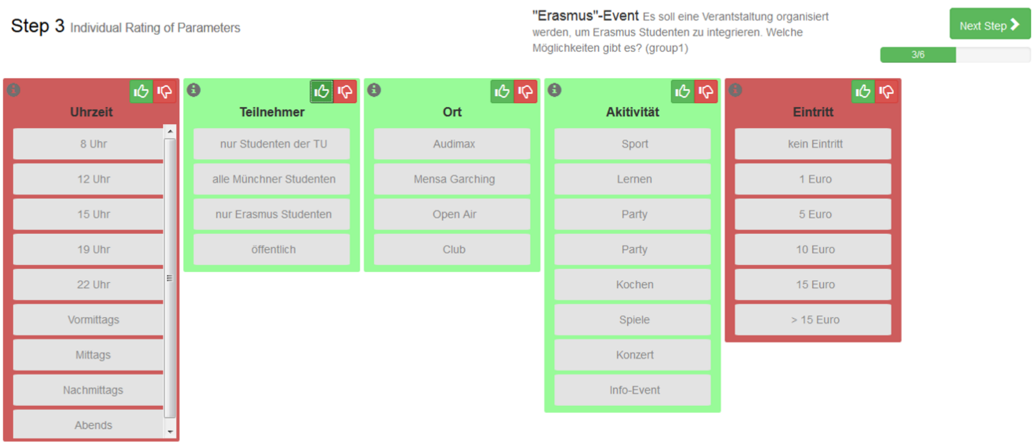


Figure 4.19.: Matrix layout in step 3 (extended)

Extended Process - Step 4

Objective of step 4 is to agree on a final set of parameters. Depending on the individual ratings of step 3, parameters of the matrix in step 4 are colored green, red or gray. The color gray implies, that the individual ratings about this parameter differ. To support the decision-making about these parameters, individual ratings can be reviewed by opening the Info Modal (see Figure 4.20). Inside the info modal the group rating can be changed. Similar to step 3, also the group rating requires a textual reason. Group rating of green or red parameter can be updated in the same way. In difference to step 3, this step allows to add or edit parameter names.

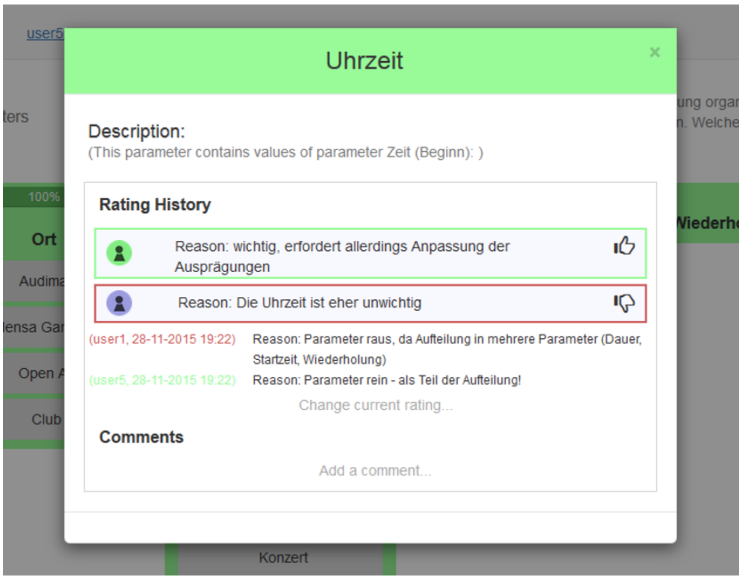
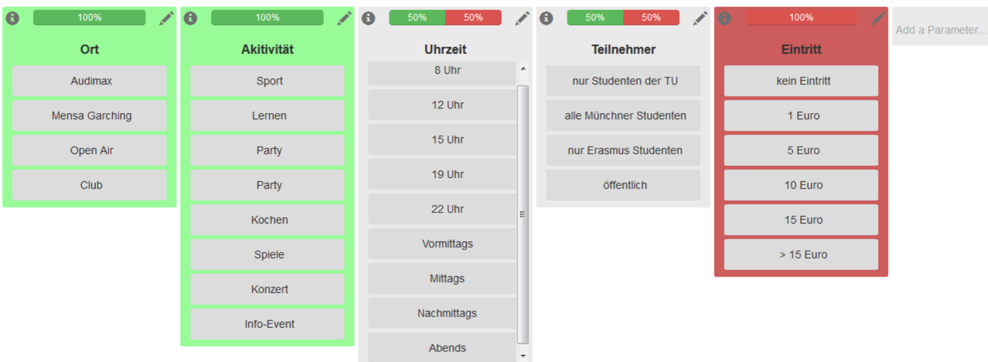


Figure 4.20.: Info modal in step 4

During the development of the prototype, the layout of this step has changed (see Figure 4.21). In order to provide a better overview about individual ratings, a small rating graph in the top of each parameter box was added. Furthermore, the new layout uses a group rating dependent order of parameters (from left to right: green, gray, red).

(a) Intermediate status (5. October 2015)



(b) Latest version

Figure 4.21.: Evolution of matrix layout in step 4

Extended Process - Step 5

The last step of the extended process focuses on the values of the remaining "green" parameters. In order to create a consistent value set, users can add, rename and delete values. In some cases it might be necessary to also revise the parameters of the matrix. Similar to step 3 of the basic process model, this step provides a "undo delete" functionality for removed parameters or values.
When satisfied with the value set of a parameter, group members can approve it by clicking the check box inside the parameter box (see Figure 4.22). As soon as the parameter or containing values changes, the check boxes of all users will be reseted as unchecked. In this way, it is ensured, that changes are in the interest of all group members.

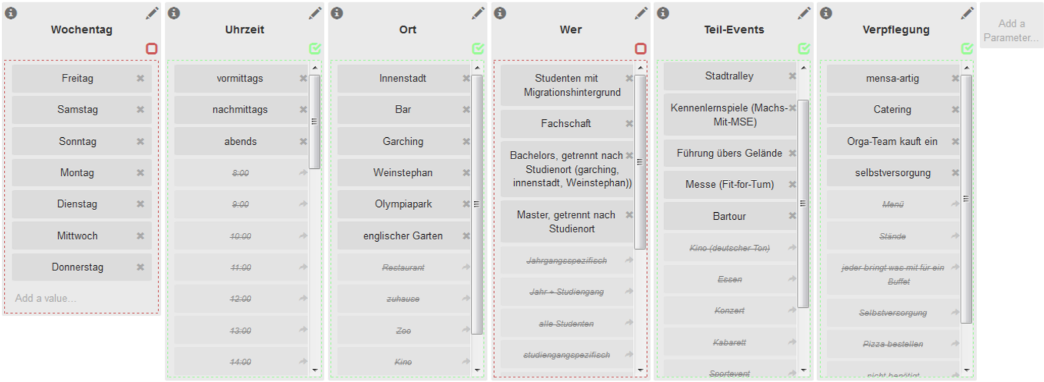
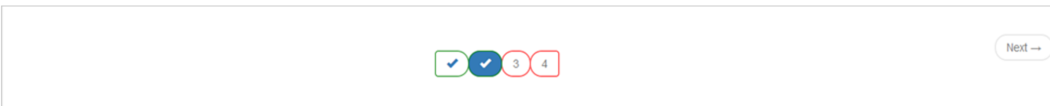


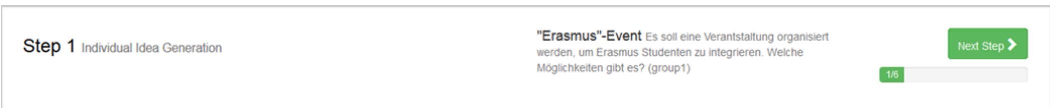
Figure 4.22.: Matrix layout in step 5

4.4.3 Process Control and Moderation

For the first version of the prototype the Bootstrap Pagination was used to show the status of the current step. Later on, the pagination was replaced by a simple next button and progress bar (see Figure 4.24). Furthermore, the new header displays a short description of the current step, as well as the title and description of the project.



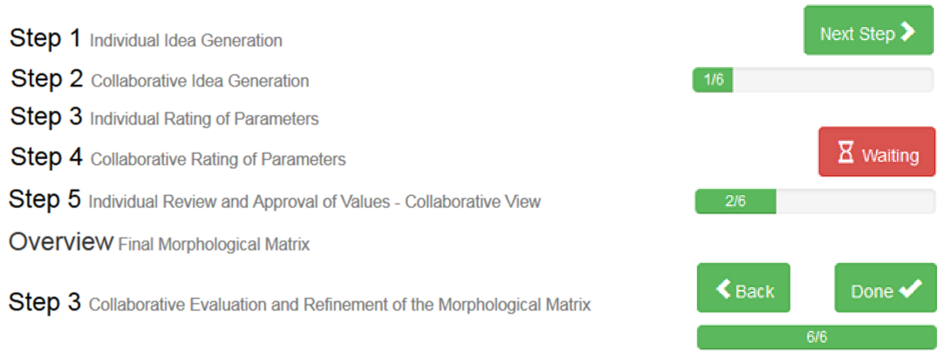
(a) Intermediate status (5. October 2015)



(b) Latest version

Figure 4.23.: Evolution of process control header

Figure 4.24 (a) lists all step headers, whereas Figure 4.24 (b) points out the different process control buttons. In order to proceed with the next step, users need to click on the "next" button illustrated at the top of Figure 4.24 (b). For each "next" button were defined, those can be found in Table A.2 in Appendix Referencesfig:details:features - A.1. Users will see the red waiting button until all other group members finished the previous step. A "back" button is only offered in the last step (Overview), the "done" button next to it will open the "Home" screen again.



(a) Step descriptions **(b)**Control buttons

Figure 4.24.: Components of process control

A core requirement of the application is, that users are always aware of the current task and which functionalities can be used to accomplish this task. Therefore, the application provides a "Step Tutorial", containing instructions for each step. Figure 4.25 depicts the tutorial of step 1, other step tutorials can be found in Appendix A - Implementation Details. The modal will appear as soon as a user enter a new step and can be reopened at any time.

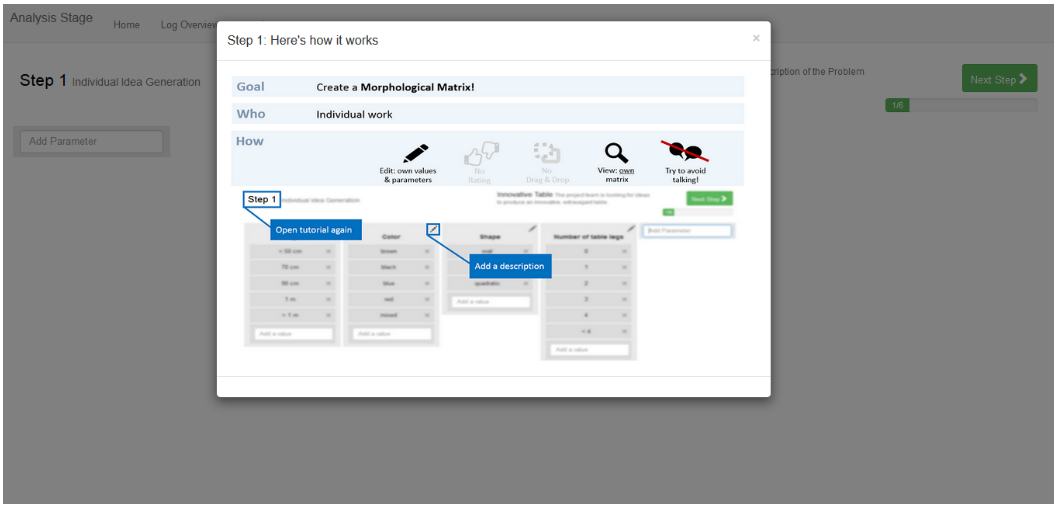
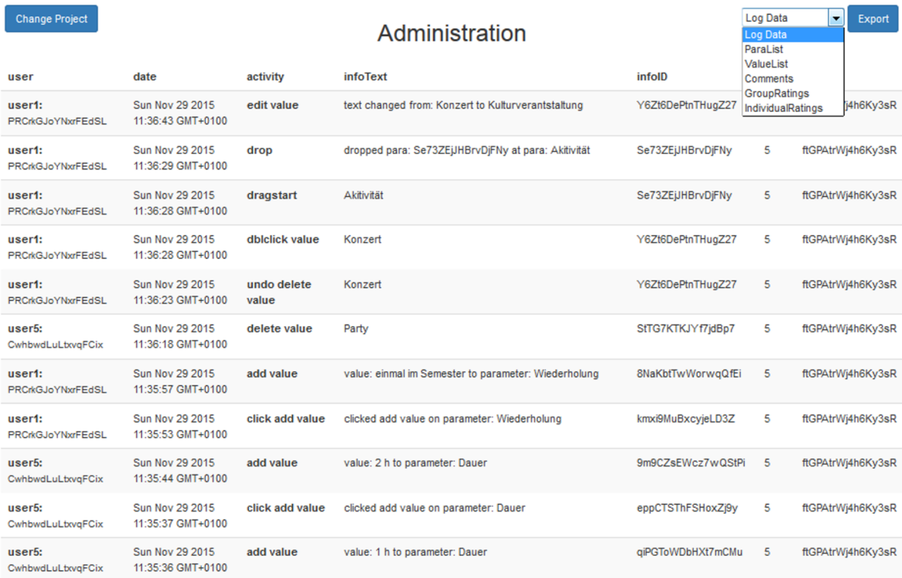


Figure 4.25.: Instruction modal of step 1

4.4.4 Administration

The user interface of the "Log Overview" is depicted in Figure 4.26. This page is only available to the admin (name: Admin and password: adminPW). The live-updating table in the center of this screen can be used to trace the event logs of a project. Therefore, the admin first has to enter a project id. The drop down on the right side can be used to export the data of a project in csv format.



user	date	activity	infoText	infoID		
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:36:43 GMT+0100	edit value	text changed from: Konzert to Kulturverantstaltung	Y6Zt6DePtnTHugZ27		j4h6Ky3sR
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:36:29 GMT+0100	drop	dropped para: Se73ZEjJHBrvDjFNy at para: Akitivität	Se73ZEjJHBrvDjFNy	5	ftGPAtrWj4h6Ky3sR
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:36:28 GMT+0100	dragstart	Akitivität	Se73ZEjJHBrvDjFNy	5	ftGPAtrWj4h6Ky3sR
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:36:28 GMT+0100	dblclick value	Konzert	Y6Zt6DePtnTHugZ27	5	ftGPAtrWj4h6Ky3sR
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:36:23 GMT+0100	undo delete value	Konzert	Y6Zt6DePtnTHugZ27	5	ftGPAtrWj4h6Ky3sR
user5: CwhbwdLuLtxvqFCix	Sun Nov 29 2015 11:36:18 GMT+0100	delete value	Party	StTG7KTKJYf7jdBp7	5	ftGPAtrWj4h6Ky3sR
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:35:57 GMT+0100	add value	value: einmal im Semester to parameter: Wiederholung	8NaKbtTwWorwqQfEi	5	ftGPAtrWj4h6Ky3sR
user1: PRCrkGJoYNxrFEdSL	Sun Nov 29 2015 11:35:53 GMT+0100	click add value	clicked add value on parameter: Wiederholung	kmxi9MuBxcyjeLD3Z	5	ftGPAtrWj4h6Ky3sR
user5: CwhbwdLuLtxvqFCix	Sun Nov 29 2015 11:35:44 GMT+0100	add value	value: 2 h to parameter: Dauer	9m9CZsEWcz7wQStPi	5	ftGPAtrWj4h6Ky3sR
user5: CwhbwdLuLtxvqFCix	Sun Nov 29 2015 11:35:37 GMT+0100	click add value	clicked add value on parameter: Dauer	eppCTSThFSHoxZj9y	5	ftGPAtrWj4h6Ky3sR
user5: CwhbwdLuLtxvqFCix	Sun Nov 29 2015 11:35:36 GMT+0100	add value	value: 1 h to parameter: Dauer	qiPGToWDbHXt7mCMu	5	ftGPAtrWj4h6Ky3sR

Figure 4.26.: "LogOverview" screen - only visible to admin

5 Evaluation

In order to evaluate the implemented web application and the underlying process model(s) an experiment was conducted. Section 5.1 deals with the experimental design. The results of the experiment will be described in section 5.2. In section 5.3 the findings were used to discuss the introduced hypotheses.

5.1 Design of experiment

Participants

Groups of 3 were assembled by randomly asking students at the faculty building for mathematics and informatics at TUM. Each of these groups consisted of two students knowing each other before and one "unknown" student. Non of the participants have heard of or even applied the morphological method before. An overview of the participants' gender, age and fields of studies is given in Table 5.1.

Gender	*Group 1*	*Group 2*	*Group 3*	*Group 4*	*Total*
Female	2		2		4
Male	1	3	1	3	8
Age					
18 years	1		1	2	4
19 years			1		1
20 years	2	1	1		4
21 years		2			2
22 years				1	1
Fields of Studies					
Mathematics			1		1
Informatics	1			1	2
Information Systems		1		2	3
Games Engineering			2		2
Management & Technology		2			2
Engineering Science	2				2

Table 5.1.: Matrix of group composition (gender, age and field of study)

Procedure

At the beginning of the experiment, a Powerpoint presentation was used to introduce the method of the morphological matrix (see Appendix B - Tutorial: Morphological Matrix). During the presentation not only the general procedure of the method was described, but also some examples for the definition of parameters and values were

given. The example problem used in that presentation was the construction of an innovative table.
Afterwards the participants were informed about the problem, they will work on next. They were instructed that they will use the application to firstly create morphological matrices in solitary and agree on a shared matrix afterwards. The shared matrix should fulfill the criteria of a morphological matrix. Group 1 and 2 used the extended process (5 steps), whereas group 3 and 4 applied the basic 3-step process.
In the end of the experiment, the participants were asked to fill out a questionnaire.

All experiments took place in a room, providing a computer for each participant. A whiteboard was used to outline the target matrix size (about 7 parameters and 2-7 values per parameter). Furthermore, each participant was provided with a printed version of the "step tutorial" (see Appendix A - Implementation Details). When participants arrived, the application was already started in Firefox, user accounts were created and logged in. Questions about the method in general, the problem, the application or the questionnaire were answered at any time. In consultation with the participants, all experiments were conducted in German.

Task
The groups were asked to solve the "Erasmus"-Event problem. Imagining they are members of a student council, they want to organize an event to integrate incoming Erasmus students. In order to generate new ideas for such an event, they should construct a morphological matrix. The final matrix should include about 7 parameters, each containing between 2 and 7 values. This limitation was given to trigger conflicts about the elimination of parameters and values.

Questionnaire
Different questionnaires were administered to the participants of groups having applied the extended process and to those having applied the basic process. The questionnaires contained 39 (extended) and 37 (basic) questions (see Figure C.7-C.10 in Appendix 5 - Evaluation). It combines questions of USE Questionnaire (Lund, 2001) and After-Scenario Questionnaire (Lewis, 1995). Most of the questions uses a seven-point Likert rating scale (from 1 *(strongly disagree)* to 7 *(strongly agree)*). In general, participants were asked about the satisfaction about the outcome (final shared matrix), group decision making, usability satisfaction, usefulness and ease of learning. Additionally, the questionnaire asked for suggestion for usability improvements and additional functionalities.

5.2 Results of experiment

The following sections present the findings of the experiment. Therefore, exported data from the application, answers of the questionnaires as well as minutes taken during the experiment were used. The total questionnaire results can be found in Appendix 5 - Evaluation (Tables C.1 - C.4).

5.2.1 Time and User Activities

Figure 5.1 depicts the time each group needed to create and agree on a shared morphological matrix. The time spent on the more divergent steps 1 & 2 is quite similar for groups 1, 3 and 4. Since a member of group 2 (user5) finished the first step after only 7 minutes, the other group members might have aborted step 1. This assumption is validated by the review of the event logs (see Figure 5.2). Furthermore, it is important to mention that during the experiment of group 3 and group 4 technical problems occurred (in step 3: about 3 minutes disconnected from server).
However, the amount of time needed for the extended process (group 1/2) seems to be lower than the amount of time needed for the basic process (group 3/4).

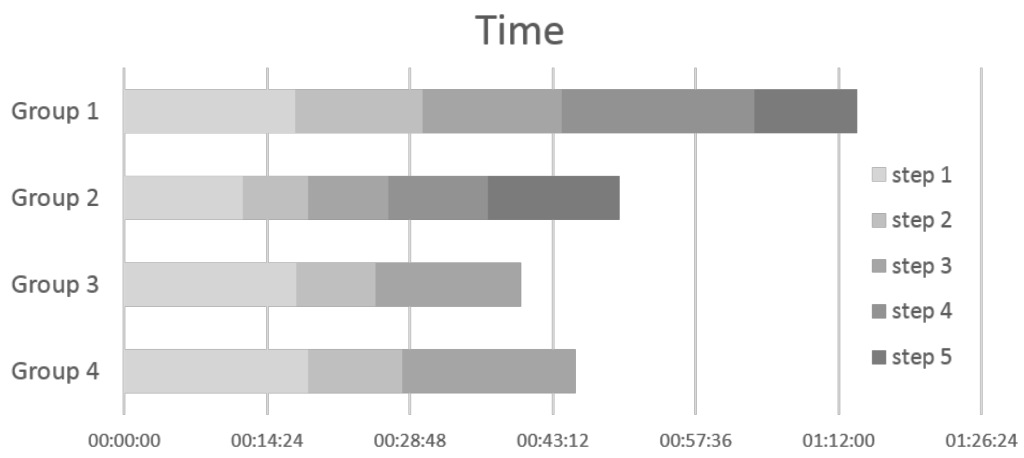


Figure 5.1.: Time needed to create and agree on a shared matrix

Step1
In general, user activities in this step decrease before finishing the step (see Figure 5.2). As assumed before, the event timeline of group 2 differ from this general observation. Users were still adding parameters and values right before clicking on the "next" button.

During step 1 mostly "add" activities and less "deleting" activities were recorded. This affirms the classification of step 1 as an step focusing on divergent thinking.

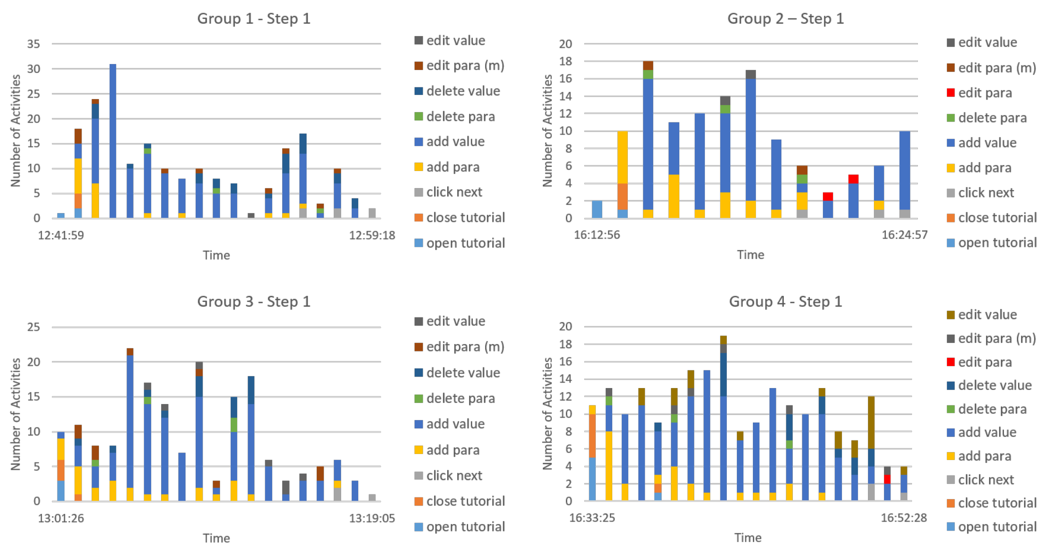


Figure 5.2.: Timeline: User activities in step 1

Step 2

Originally, the objective of step 2 was to extend the shared matrix by adding parameters and values. Since dry runs of the experiment revealed that especially obvious duplicates (e.g. parameters: "Location" and "Where?") complicate the individual rating system of step 3, a drag&drop feature was added to this step. Doing this, the experimental groups mainly focused on merging parameters, instead of adding parameters and values (see Figure 5.3).

Reviewing data of merged parameters, it was recognized, that not only obvious duplicate parameters were merged (e.g. "Time" and "Frequency"). Furthermore, group 1 and 4 deleted duplicate values of merged parameters, which was not meant to be task of this step. The small number of added values, might be caused by the fact, that group members added very similar parameters in step 1. This way the intended effect of cognitive stimulation might have been impaired.

Contrary to the definition of step 2 as a divergent thinking step, the resulting activity timeline alludes that in this step convergent thinking was dominating.

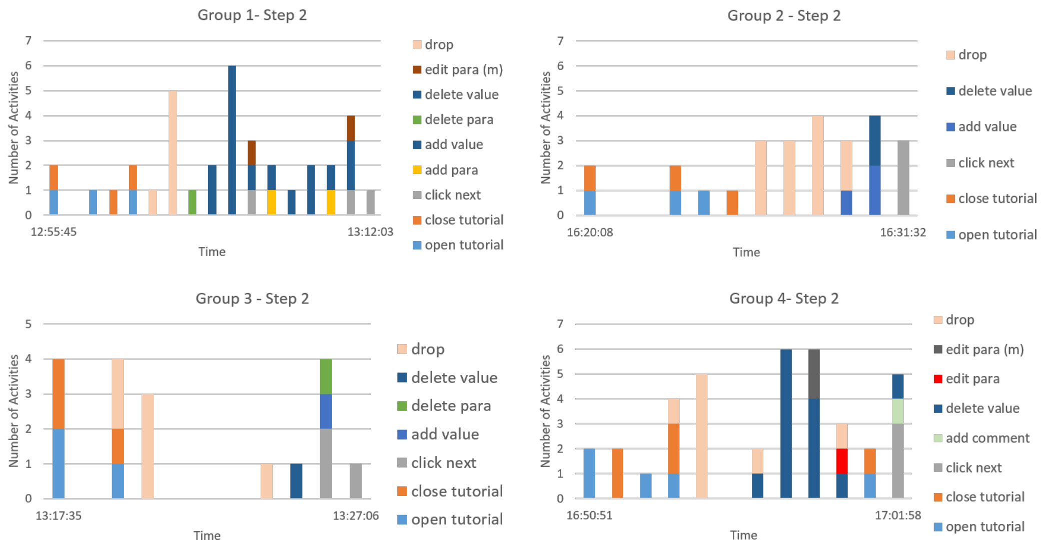


Figure 5.3.: Timeline: User activities in step 2

Step 3 (basic)

The activity timeline of group 3 and group 4 is depicted in Figure 5.4. Due to technical problems in both groups, the process of step 3 was interrupted for about 3 minutes. The fact, that both diagrams contain less "undo delete" activities indicates, that group 3 and 4 had less arguments regarding the values or parameters of the final matrix. This assumption matches the given answers in the questionnaire (see section 5.2.3).
Both activity timelines do not contain a lot of "add" activities, this corresponds to the classification of step 3 as a step focusing on convergent thinking.

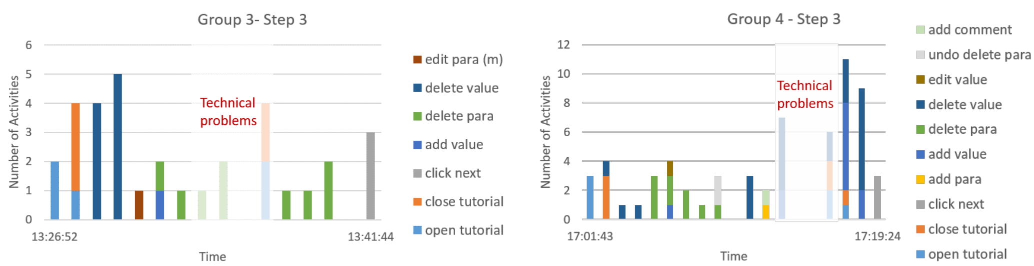


Figure 5.4.: Timeline: User activities in step 3 (basic)

Step 3, 4 & 5 (extended)

Figure 5.5 illustrates the activity timelines of step 4 and step 5. Comparing the activities of group 1 and group 2, two different approaches for accomplishing the tasks could be noticed. Whereas group 2 focused on rating in step 4 and revised (add and edit) the parameter set in step 5, group 1 finished the refinement of parameters in step 4 .

The "checkmark"-functionality provided in step 5, was meant to be used as a mechanism to ensure all group members are satisfied with the value set of a parameter. Since all participants "checked" parameters in the end of step 5, it can be assumed, that the functionality is useless and was only used to fulfill the preconditions of the "next" button (all boxes need to be checked to finish this step). Investigating the context of the usage of "undo delete" functionalities in step 5, showed that most were caused by collaborative coordination problems.
Diagrams of step 3 (extended) can be found in Appendix C - Evaluation (Figures C.1 and C.2).

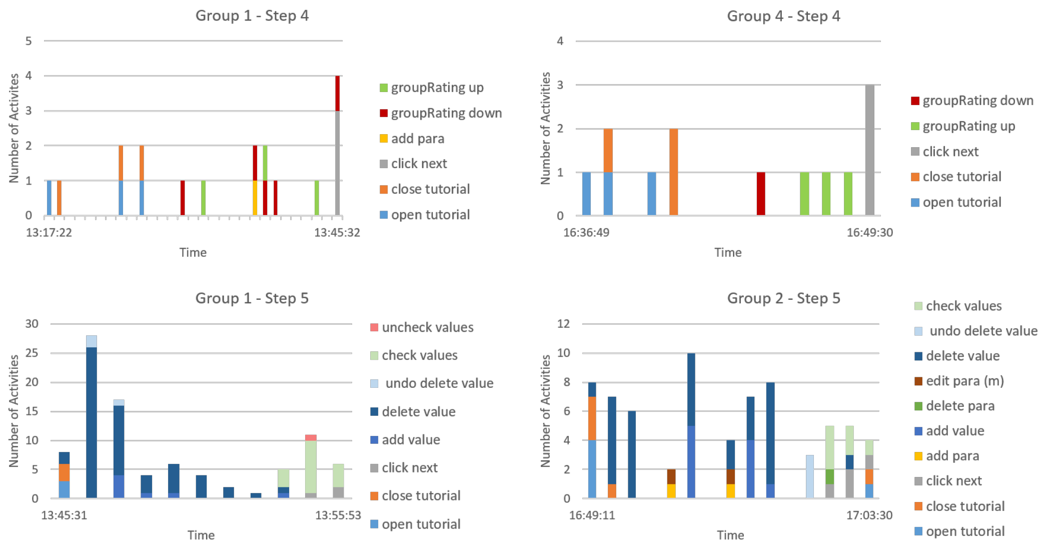


Figure 5.5.: Timeline: User activities in step 4 and 5 (extended)

5.2.2 Final Matrices

The final matrices of all groups contain similar parameters about time, location, participants and the main activity of the event. Additionally, every matrix is extended by some more "special" parameters (e.g. catering or entrance fee). The final matrix of group 1 is illustrated in Figure 5.6, whereas Appendix C - Evaluation contains the final matrix of all groups.
The quality of matrices 1-3 is acceptable, although not all values were defined correctly (MECE-Rule). On contrary, the final matrix of group 4 contains parameters, which does not even follow the basic rules of a morphological matrix (e.g. "Goal" and "additional program item"). Moreover, the number of values included in matrix 4 does not confirm with the given guidelines (2-7 values per parameter).

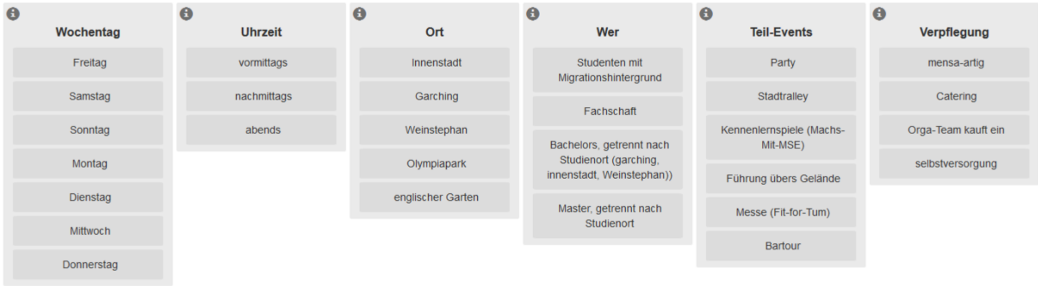


Figure 5.6.: Final matrix of group 1

Since the groups worked on a rather simple problem statement, they generated similar ideas. This results in matrices containing a high number of merged parameters (see Table 5.2). Table 5.3 summarizes in which step parameters and values of the final matrix were added. Most ideas were generated in the first step. Regarding to the parameters added in step 3 or 5, it is important to mention, that those are not presenting new ideas, but a recreation or division of previously deleted or merged parameters.

Group1	*user1*	*user2*	*user3*	*merged*	*total*
Parameters of final Matrix	0	0	2	4	6
Values of final Matrix	4	10	15	-	29
Group 2	*user4*	*user5*	*user6*	*merged*	*total*
Parameter of final Matrix	1	1	2	3	7
Values of final Matrix	19	13	12	-	44
Group 3	*user7*	*user8*	*user9*	*merged*	*total*
Parameter of final Matrix	0	1	3	3	7
Values of final Matrix	9	12	29	-	50
Group 4	*user10*	*user11*	*user12*	*merged*	*total*
Parameter of final Matrix	3	2	0	4	9
Values of final Matrix	35	25	6	-	66

Table 5.2.: Final matrix composition - creator of parameters and values

Group1	*step1*	*step 2*	*step 4*	*step 5*	*total*
Parameters of final Matrix	6	0	0	0	6
Values of final Matrix	22	0	-	7	29
Group 2	*step 1*	*step 2*	*step 4*	*step 5*	*total*
Parameter of final Matrix	5	0	0	2	7
Values of final Matrix	33	1	-	10	44
Group 3	*step 1*	*step 2*	*step 3*		*total*
Parameter of final Matrix	7	0	0		7
Values of final Matrix	48	1	1		50
Group 4	*step 1*	*step 2*	*step 3*		*total*
Parameter of final Matrix	8	0	1		9
Values of final Matrix	55	0	11		66

Table 5.3.: Final matrix composition - step in which parameters and values were created

In the first part of the questionnaire participants were asked about their satisfaction, concerning the created matrix and containing parameters/values. In general, in all groups the satisfaction seemed to be very high. Moreover, group 1 and 2 seemed to be a little bit more pleased about there outcome in general. This might not only be related to the process model they applied, but also the time they spent on the task.

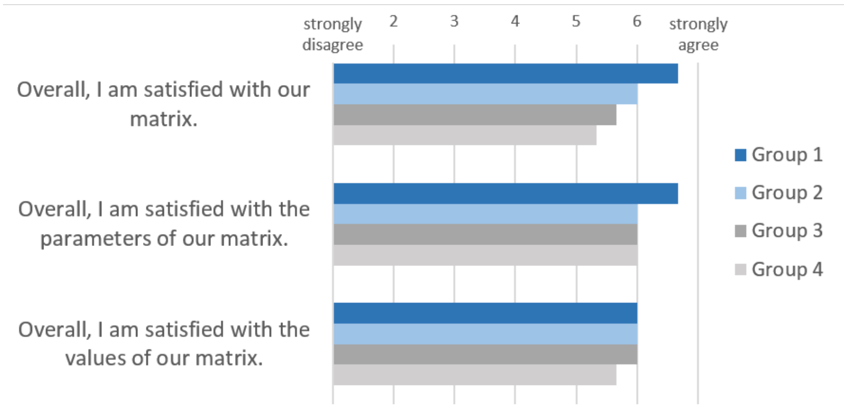


Figure 5.7.: Average group rating of statements about satisfaction concerning the final matrix

5.2.3 Group Decision Making

In order to agree on a shared matrix, groups had to select and decide on a range of parameters. Therefore, the extended process model, provide a rating system. The offered "flags" were used only for 5 of 60 ratings (2x "Same as" and 3x "Conflict with"). In order to circumvent the required reasoning of other ratings, some users entered empty spaces. Only 3 group members of the two groups typed in a reason for all ratings.
In step 4 the group members had to solve the conflicting ratings. Generally, participants rated it as helpful to review the individual ratings in order to decide about the final parameter set. Almost all group ratings (10 of 11) conform with the majority of the individually rankings. All given group ratings referred to conflicting ("gray") parameters, non of the calculated group ratings ("green" and "red" parameters) was changed.

The basic process does not provide any support for group decision making. Consequently, group members itself had to manage the information exchange during discussion in step 3. For this purpose, the members of group 3 moved to the computer of user 8 and went through the list of parameters. The discussion of group 4 addressed only a few parameters. The group had disagreements and a long discussion about the relevance of the "price" parameter. In the end, the group applied a majority voting about this parameter.

Overall, all groups seemed to be satisfied about the general group decision making (see Figure 5.8). Concerning the question of how easy it was to agree on a shared matrix, the participants of group 2 had really different impressions. Whereas user 4 found it hard to agree on a shared matrix (rating: 2), user 5 strongly agree with the last statement of Figure 5.8 (rating: 7).
It does not seem, that the process model influences participants' satisfaction about decision making.

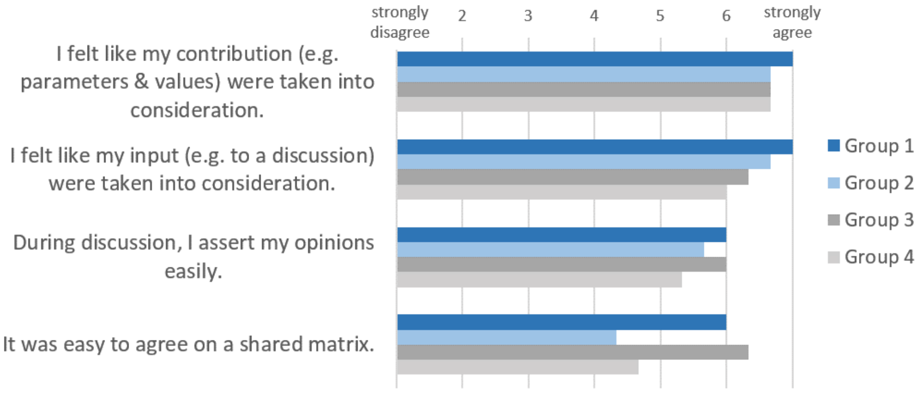


Figure 5.8.: Average group rating of statements about group discussion

Asking about the occurrence of disagreements during decision making, groups applying the extended process stated to have had more disagreements, than groups applying the basic process (see Figure 5.9).
Since the extended process forces participants to rate every parameter individually, all conflicting opinions were detected automatically. This might be the reason for group 1 and 2 stating to had more disagreements than participants of group 3 and 4. It is important to mention, that Figure 5.9 only presents the average value of each group and that individual statements of some groups differ (e.g. individual ratings of group 1 "... about values": 7, 5, 3).

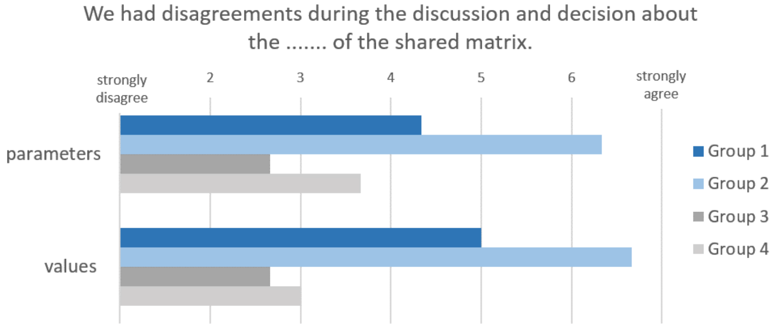


Figure 5.9.: Average group rating of statements about the occurrence of disagreements

5.2.4 Ease of Learning, Usefulness and Usability Satisfaction

The questionnaire also includes questions about ease of learning. The questions does not refer to the process model, but to the method of the morphological matrix in general. However, participants applying the basic process, seems to feel less skillful, compared to the participants, who applied the extended model.

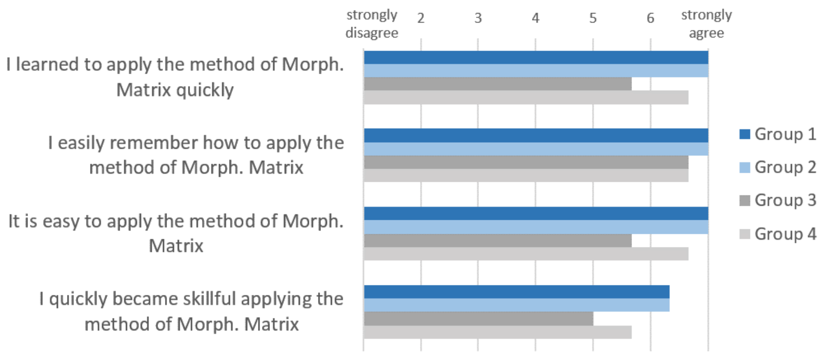


Figure 5.10.: Average group rating of statements about the ease of learning

Questions of Figure 5.11 addresses the perceived usefulness. Most participants evaluated the application as useful, but also claim to miss functionalities (see section 5.2.5). Moreover, only one participant stated to prefer the usage of a whiteboard the next time. They were also asked to list pros and cons of the two alternatives. Table 5.4 shows a selection of these lists.

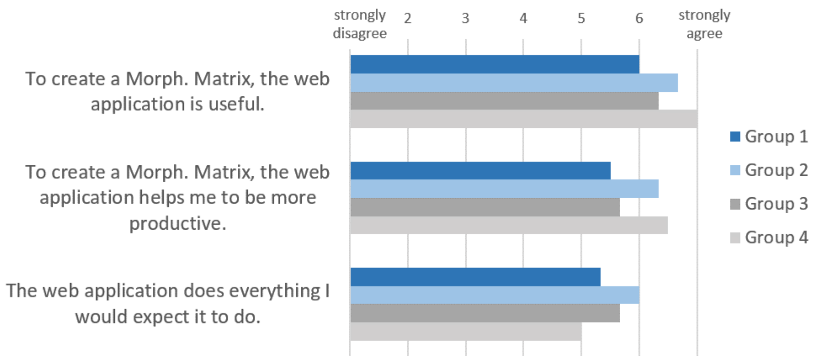


Figure 5.11.: Average group rating of statements about the app's usefulness

Pro Whiteboard	Contra Whiteboard
- high creativity - clear structure, since only one is writing at one time	- erasing is more work - difficult to change - difficult to work simultaneously - loosing unconventional ideas
Pro Web App	**Contra Web App**
- contains helpful information - every opinion counts - less time - easy to collaborate - generation of creative ideas	- less communication (->loosing good ideas) - bugs / shortcomes in usability - less interactive - not able to see who changed what - time-consuming in larger groups - sometimes impersonal

Table 5.4.: Pros and cons of whiteboard based procedures vs. application of the web application

The questions depicted in Figure 5.12 agree with the previous findings, that the users seem to be satisfied with the web application. Compared to the groups 1 and 2, group 3 and 4 (basic process) seemed to be more satisfied with the time it took to create the matrix. This corresponds to the fact, that this process took less time.

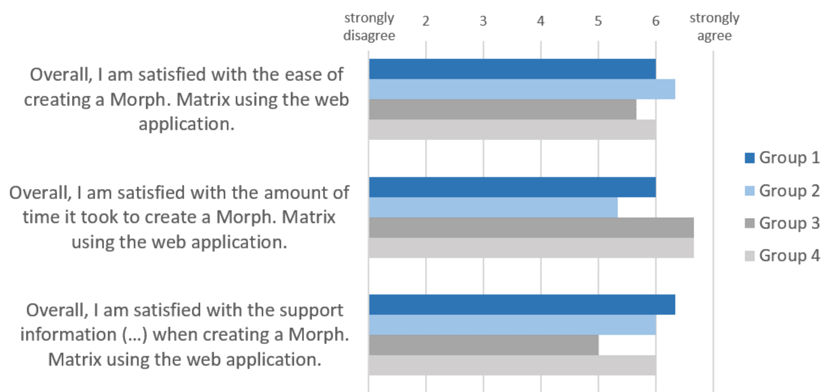


Figure 5.12.: Average group rating of statements about the overall satisfaction with the web application

The participants also made some suggestions to improve the application's usability (see Table C.1 - C.4 in Appendix 5 - Evaluation). Not only small changes of the user interface were suggested (e.g. close modals by pressing "Esc" or more hints about what happened, when a button is clicked), but also some more task related suggestions were made. A user of group 2 would like to see the current progress of other team members. A member of group 1 would restrict the ability to modify the matrix - only one team member should be able to modify the matrix during the collaborative steps. A member of group 4 would add a "undo delete" functionality to step 2.

5.2.5 Features

During the experiments, description and comment features were used rarely. In the questionnaire the participants stated to prefer face-to-face communication, instead of adding comments.
In the last question participants were asked to suggest additional functionalities. A user proposed a voice-to-voice functionality to support distributed teams. In order to improve drag&drop, a hand icon as well as a horizontally scrolling was suggested. Furthermore, a user would like to have a functionality to move parameters and values in order to align similar ones to each other. A member of group 4 suggested a functionality to export the results into .jpg or .pdf and also make it possible to share or invite new group members. Related to the underlying process models, a member of group 2 (extended process) would add an additional evaluation step between step 1 and step 2.

5.3 Discussion

Using the findings of the experiments the introduced hypotheses (see chapter 3.1.3) will be discussed in the following section.

Using the proposed extended process model, the group performance of the Analysis Stage is less affected by...

H1. ...motivation losses like social loafing and free riding.
These motivation losses should be prevented through the subdivision into individual and collaborative steps. Doing this, every group member was forced to generate ideas in step 1 and rate all parameters in step 3.
On observation of experimental findings, it becomes apparent, that all group members participate actively and generated ideas in step 1. Nevertheless, the fact that not all group members reasoned their ratings properly (step 3), might indicate the occurrence of motivation losses.
In order to prevent evaluation apprehension, users' contributions were shown anonymously. In this way motivation losses might be encouraged. The conducted experiments used a small group size of three people, which were all located in a single room. In this way, especially creators of individual ratings but also creators of parameters and values were identified easily.

H2. ...production blocking and cognitive restrictions.

In order to prevent production blocking and cognitive restrictions the divergent thinking stages were decomposed into step 1 and step 2.
The conducted experiments of this thesis compared two process models, both containing the decomposition into step 1 and 2. To corroborate the hypothesis, this experimental design was not useful, since it did not contain any equation groups. But the implemented decomposition refers to the concept of Nominal Groups, mostly used in the context of Brainstorming. This concept has been tested successfully in a number of studies (Diehl et al., 1987).
Besides the purpose of preventing cognitive restrictions, the proposed process models still aim to benefit from cognitive stimulation. Here it is important to mention, that during the experiment very few ideas were added in step 2. This finding reveals a lack of cognitive stimulation. Since the problem statement used for the experiment was rather simple, generated ideas of step 1 were very similar. This might have evoke the lack of cognitive stimulation. Another reason for this might be, that step 2 contains two tasks, combining divergent and convergent thinking. Most groups focused on the task of merging parameters instead of generating new ideas.

H3. ...the issue of hidden profiles.

In order to solve hidden profiles, it is necessary, that each group member shares all available information. Therefore, step 3 was added to the extended process model. In this step group members were asked to rate all parameters individually. Each rating requires a reason, which was shown in step 4.
The findings described in section 5.2 (see Figure 5.9) show, that groups using this rating system had more disagreements. This may be an indicator for an increased number of shared opinions and (conflicting) information.

Even if the proposed models seem to prevent process losses, a limitation of scalability was detected during the experiments. Due to the decomposition of the divergent thinking stage, a number of duplicate parameters were created. Concerning the shared matrix in step 2, this results in a lack of transparency. Since this problem already occurred in comparatively small groups of 3, it might be necessary to revise the process model.
However, the conducted experiments were mainly designed to test the web application's usability. In order to test the hypotheses it requires experiments, which also investigate the behavior of groups applying the standard process. Furthermore, the conducted experiment is limited in its sample size. It only studied the behavior of 4 groups, whose members were all students at TUM. Non of the participants applied the morphological method before. Consequently, they did not have any reference to evaluate the procedure properly. Due to these facts, the validity of the findings, presented and discussed, above is limited.

Conclusion

6

6.1 Summary

The purpose of this thesis was to design an extended process model for the Analysis Stage of the MA and to implement a prototypical web application supporting this process model. Therefore, the literature of the MA and it's application as well as the literature of group performances and it's biasing factors were reviewed. Focusing the Analysis Stage of the MA, relevant process losses and gains were identified. In chapter 3 two process variations for the Analysis Stage were proposed. In order to prevent the occurrence of process losses, both variations combine individual and collaborative work as well as divergent and convergent thinking. Following, the requirements for a web application supporting the proposed process models were elected. The resulting implementation was described and illustrated in section 4. Finally, an experiment was conducted to evaluate the web application and underlying process models. The findings of the experiment reveal some shortcomings of the proposed process models (e.g. lack of scalability). Furthermore, participants of the experiment suggested a number of usability and user interface improvements, which should be considered in future work.

6.2 Future Work

In this thesis collaborative process models were proposed and a web application was implemented. During evaluation some shortcomings were revealed, which require a revision of the prototype. Moreover, there is a need for further evaluation.

Revising web application
First of all, the usability of the provided drag&drop feature needs to be improved. Therefore, a hand icon should be displayed when dragging a parameter. In order to enable merging of parameters, which are located in different viewing areas, dragging a parameter should also trigger horizontally scrolling.
Secondly, the process control should be improved in a way that waiting time, especially between step 1 and step 2, will be reduced. One possible approach is to make the progress of all users visible to all group members, as a participant of the experiment suggested.
Since the progress graph was removed, there is a need for an additional feature

encouraging social competition. An activity timeline is another feature to consider, which is not implemented yet. The timeline could display last user actions (e.g. "user xy deleted parameter z") in order to improve collaboration of distributed teams. In addition, participants of the experiment suggested a number of user interface improvements and further functionalities (see section 5.2.5), which could improve the usability and usefulness of the application.

Further evaluation

Due to the experimental design (see chapter 5.1), the conducted experiments could not be used to evaluate the web application properly. As mentioned in chapter 5.3, there is a need for further experiments, designed to test the introduced hypotheses. Therefore, investigating the behavior of groups applying the standard process, assigning predefined characters as well as providing monetary incentives might be useful. It should also be considered to use audio rerecording to evaluate the behavior of participants more precisely. Apart from that, future research should consider the usage of experienced participants to evaluate the procedure.

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Appendices

A Implementation Details

	step1	step 2	step 3 (basic)	step 3	step 4	step 5
Add Parameter	x	x	x		x	x
Rename Parameter	x	*(own)*	x		x	x
Add Description to Parameter	x	*(own)*	x		x	x
Delete Parameter	x	*(own)*	x		x	x
Undo Delete Parameter			x			x
Add Value	x	x	x			x
Rename Value	x	(own)	x			x
Delete Value	x	(own)	x			x
Undo Delete Value			x			x
Drag&Drop		x	x		x	x
Add Comment		x	x	x	x	x

Table A.1.: Overview of features provided during the process of Analysis Stage

Preconditions of "next" button	
Step 1	at least **1 parameter** & **2 values** per parameter
Step 2	at least **2 parameter** & **2 values** per parameter
Step 3 (basic)	at least **2 parameter** & **2 values** per parameter
Step 3	**individual rating** for each parameter (all parameters green/red)
Step 4	**group rating** for each parameter (all parameters green/red) & at least **2 "green" parameters**
Step 5	all check boxes **checked** & at least **2 parameter** & **2 values** per parameter

Table A.2.: Preconditions of "next" buttons

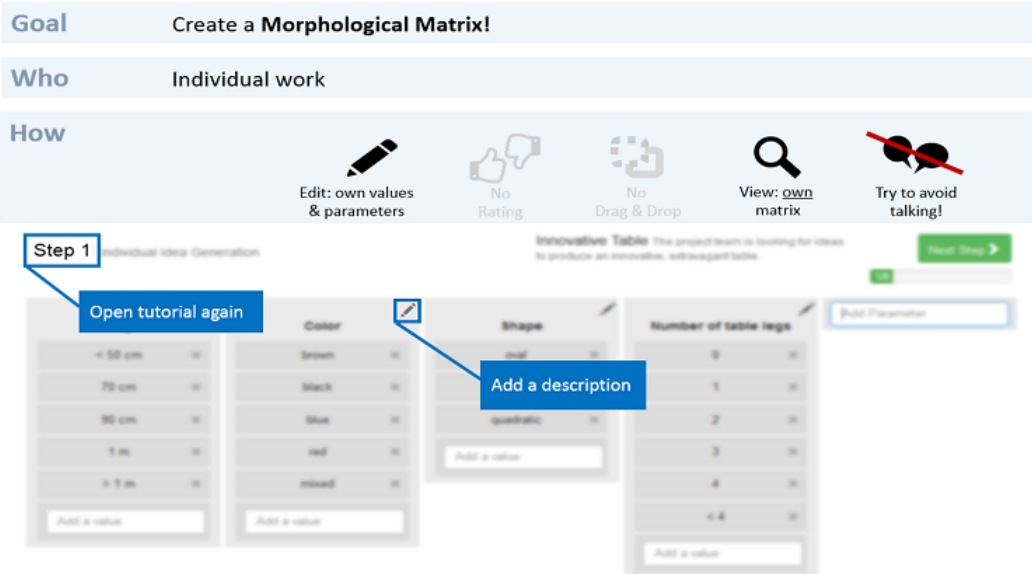


Figure A.1.: Tutorial of Step 1

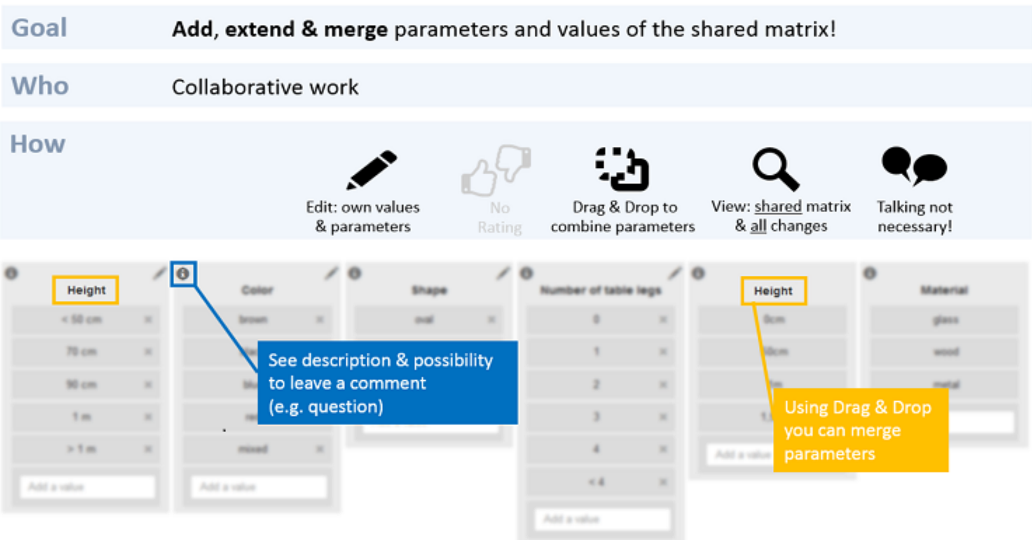


Figure A.2.: Tutorial of Step 2

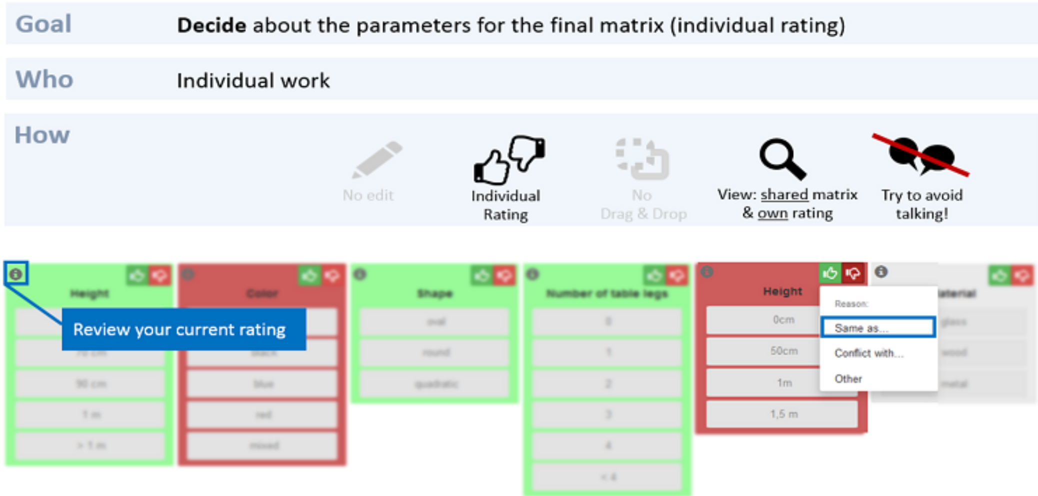


Figure A.3.: Tutorial of Step 3

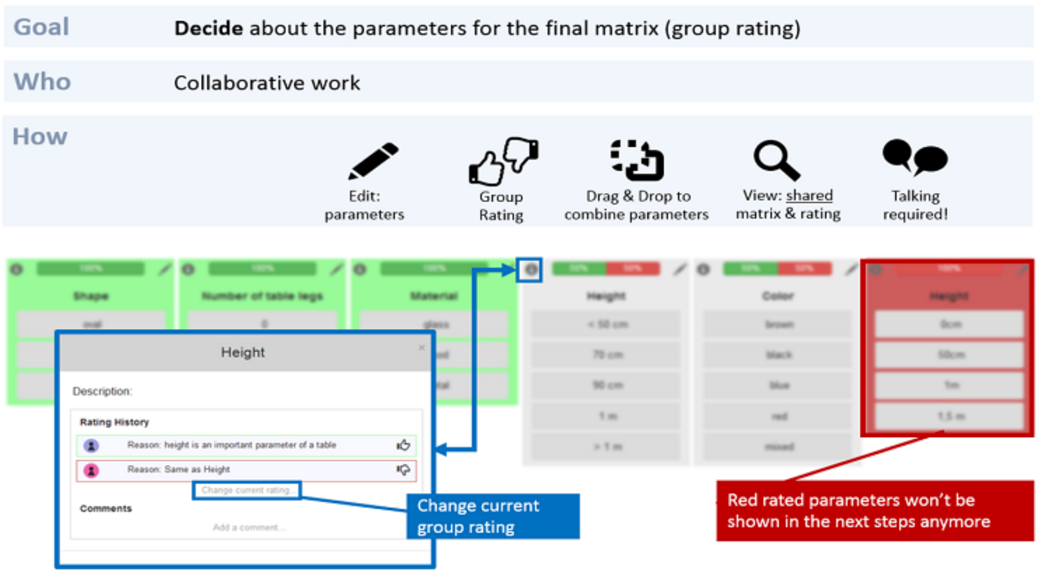


Figure A.4.: Tutorial of Step 4

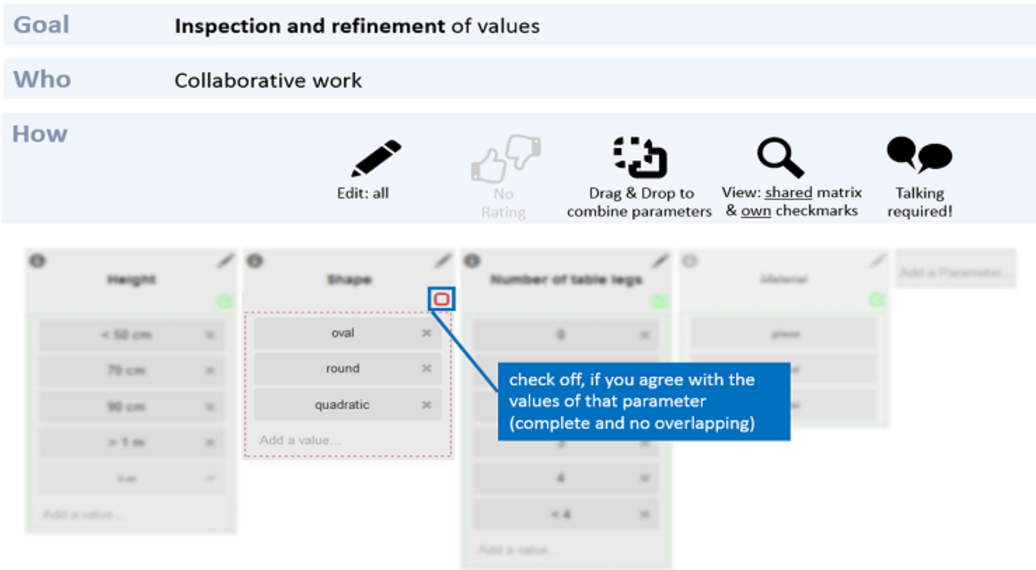


Figure A.5.: Tutorial of Step 5

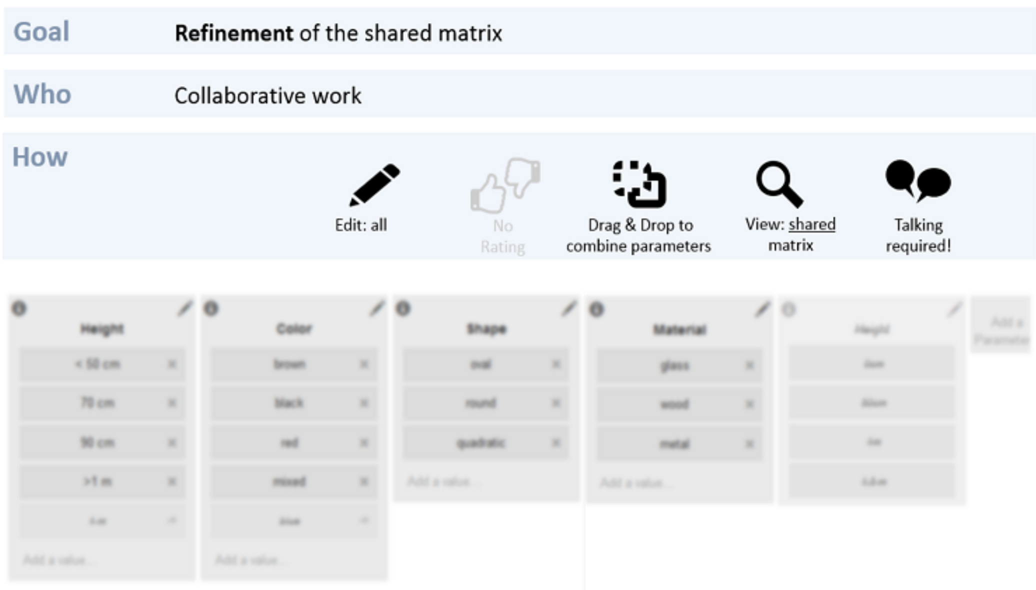


Figure A.6.: Tutorial of Step 3 (basic process)

Tutorial: Morphological Matrix

B

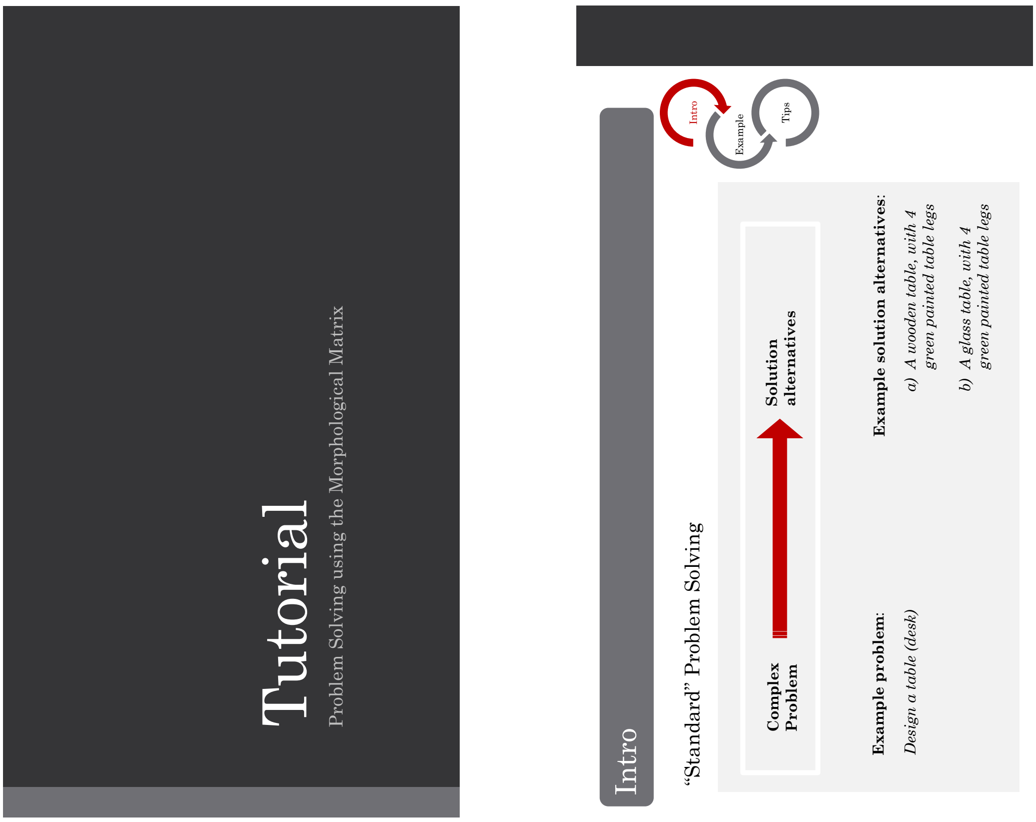


Figure B.1.: Tutorial: Morph. Matrix - Slides 1 and 2

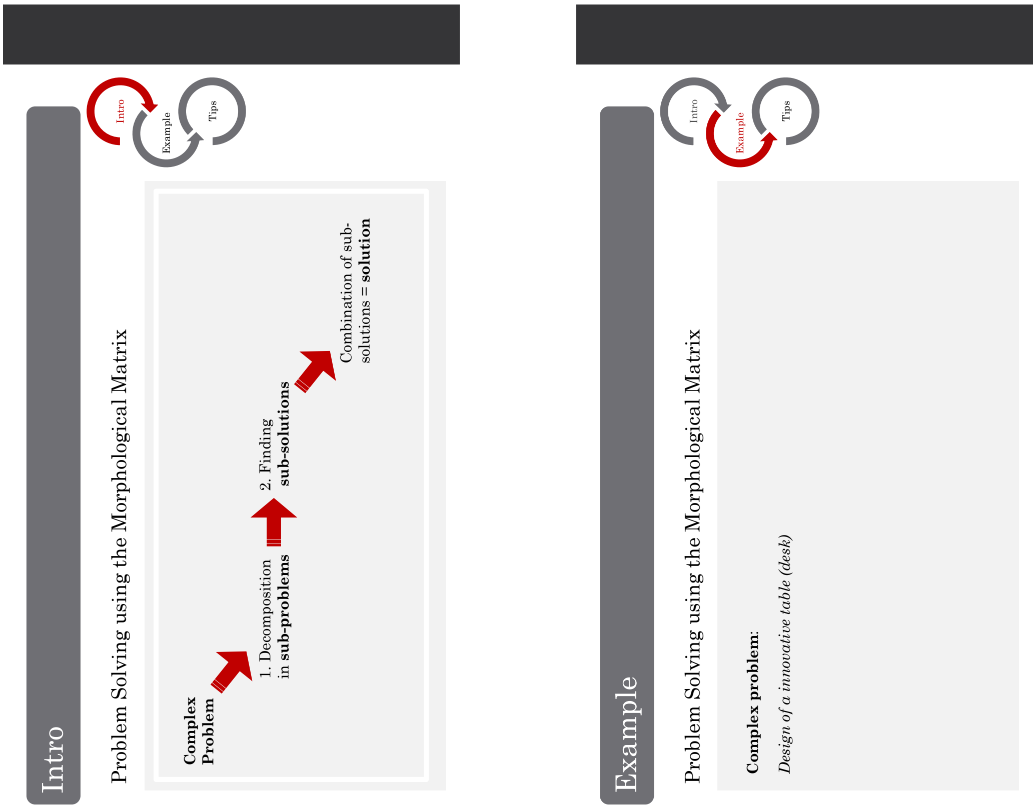


Figure B.2.: Tutorial: Morph. Matrix - Slides 3 and 4

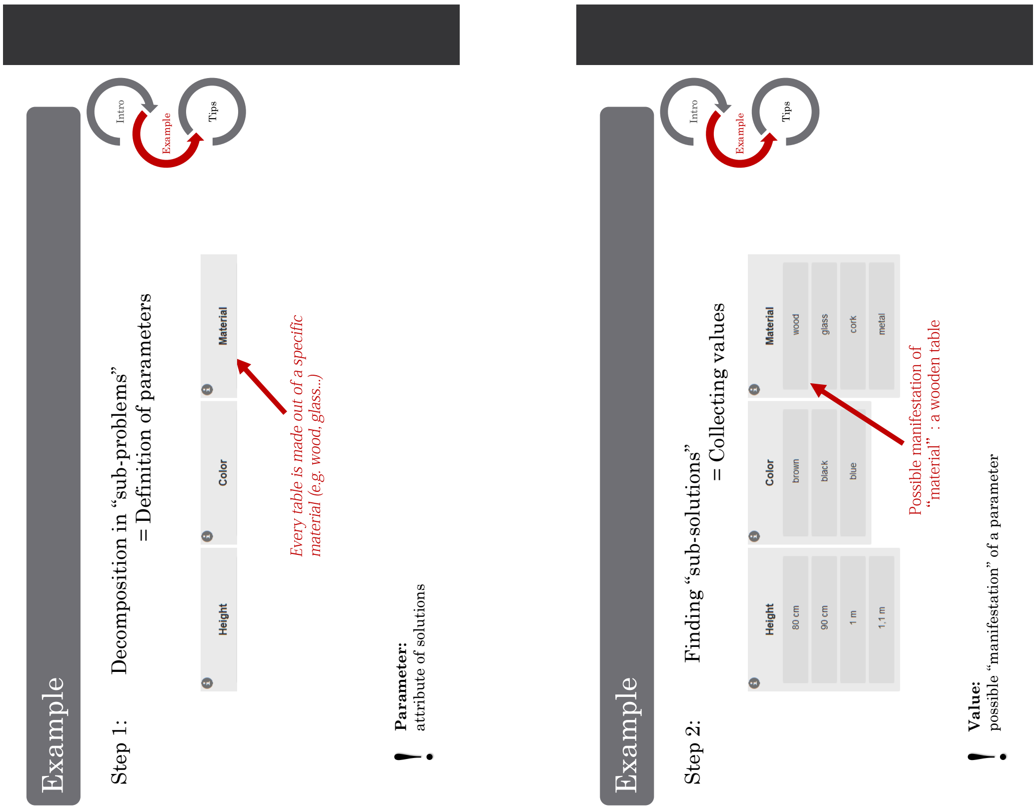


Figure B.3.: Tutorial: Morph. Matrix - Slides 5 and 6

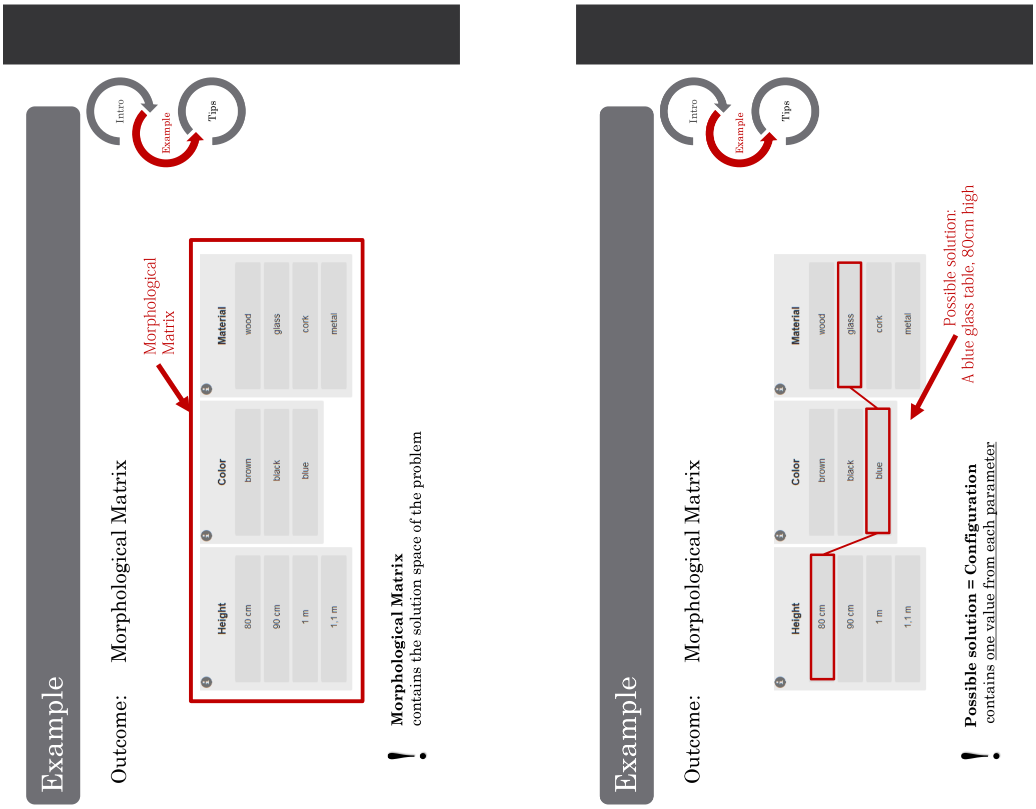


Figure B.4.: Tutorial: Morph. Matrix - Slides 7 and 8

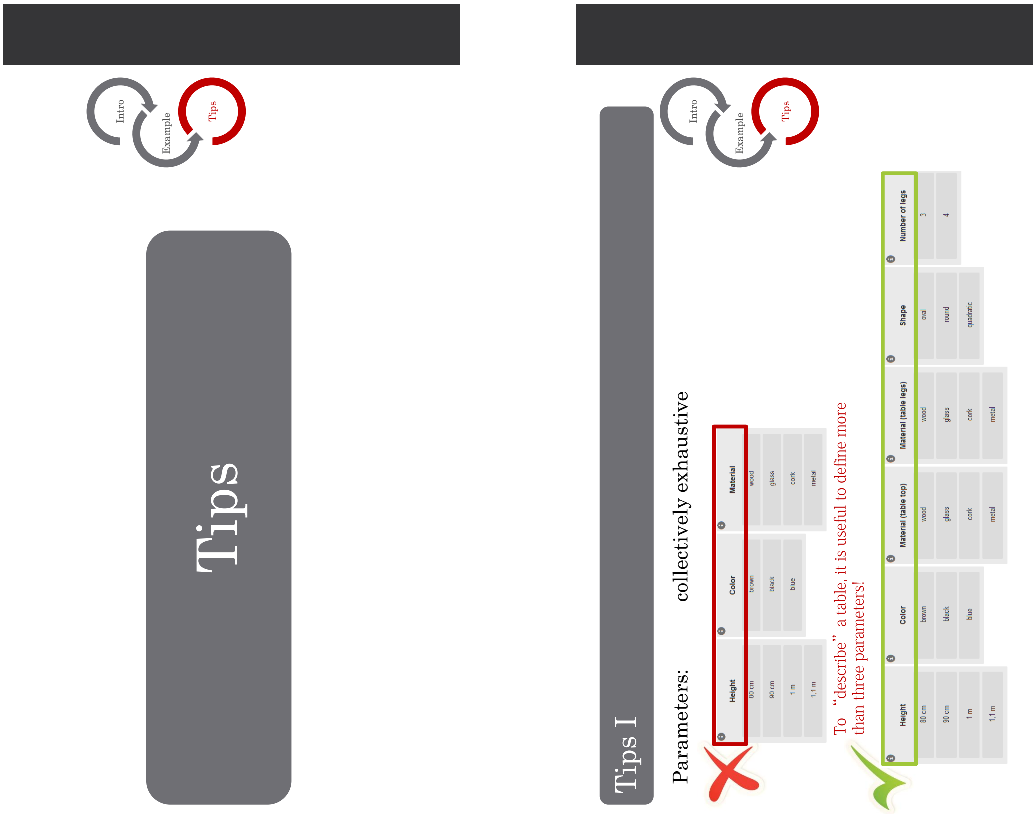


Figure B.5.: Tutorial: Morph. Matrix - Slides 9 and 10

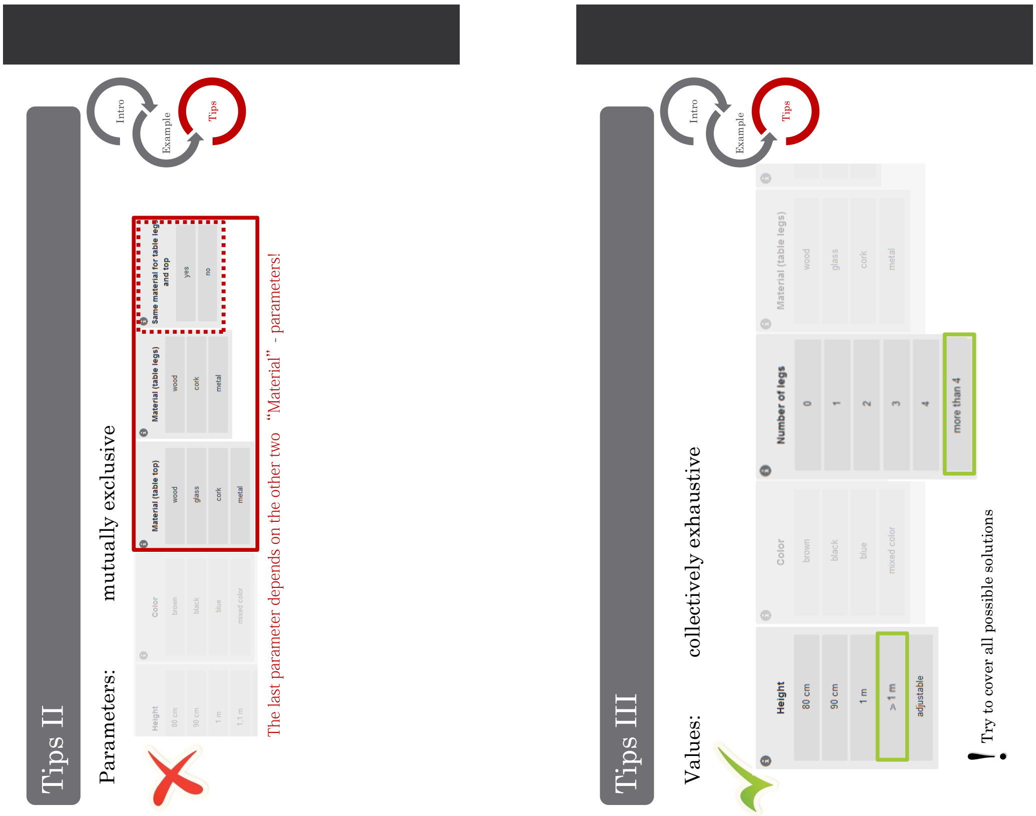


Figure B.6.: Tutorial: Morph. Matrix - Slides 11 and 12

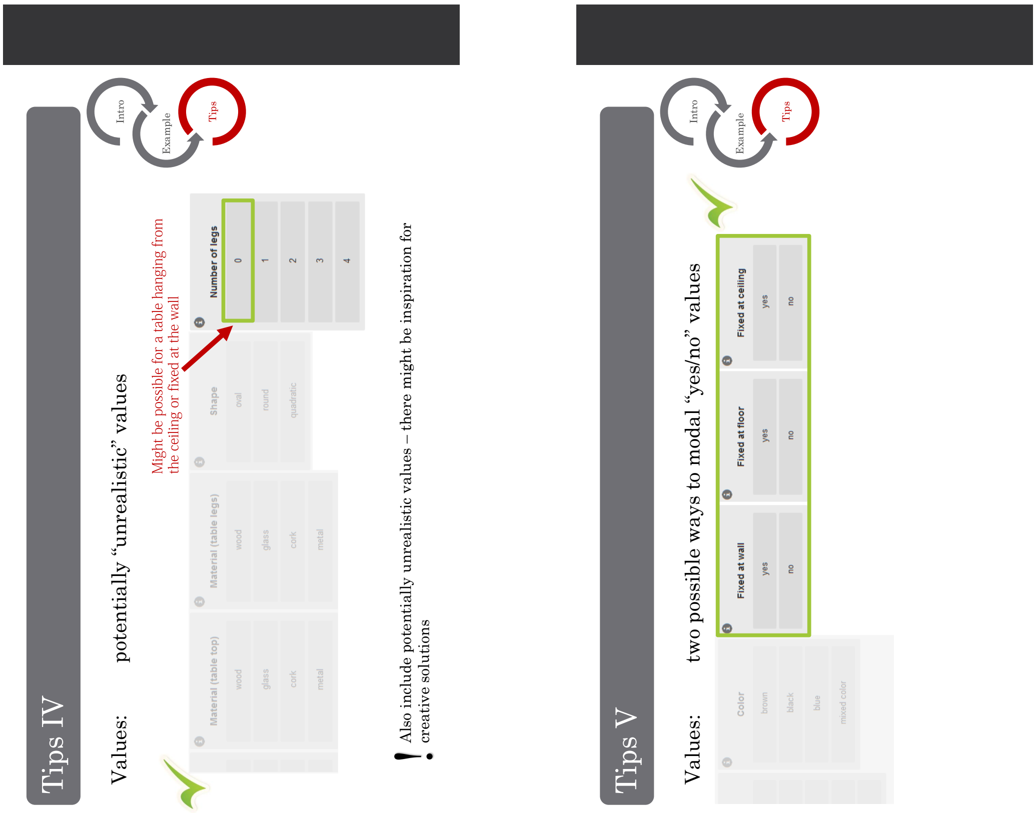


Figure B.7.: Tutorial: Morph. Matrix - Slides 13 and 14

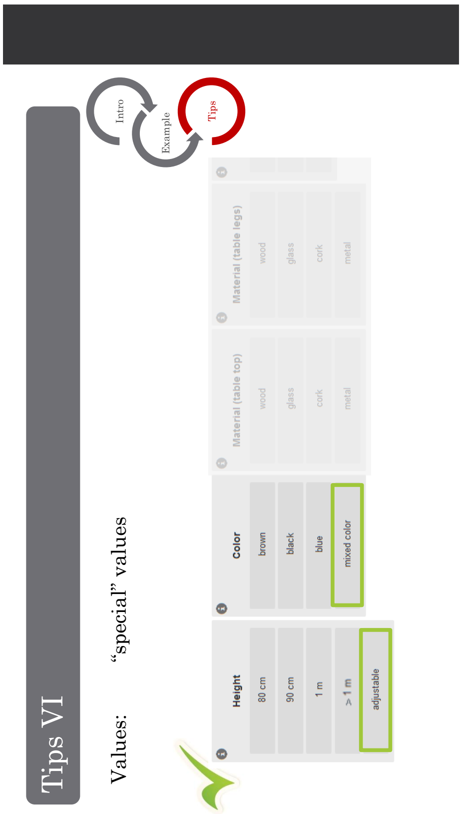


Figure B.8.: Tutorial: Morph. Matrix - Slides 15 and 16

C Evaluation

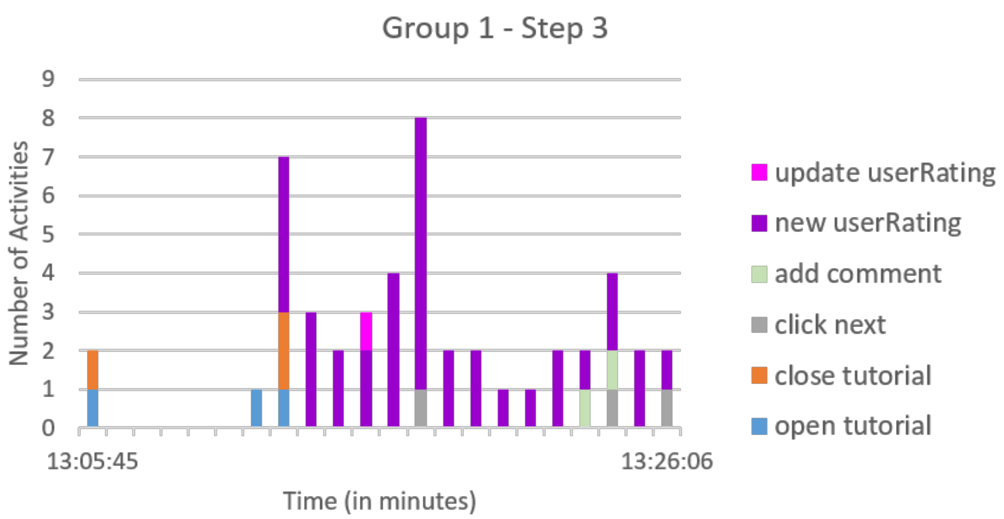


Figure C.1.: Timeline: User activities in step 3 (group 1)

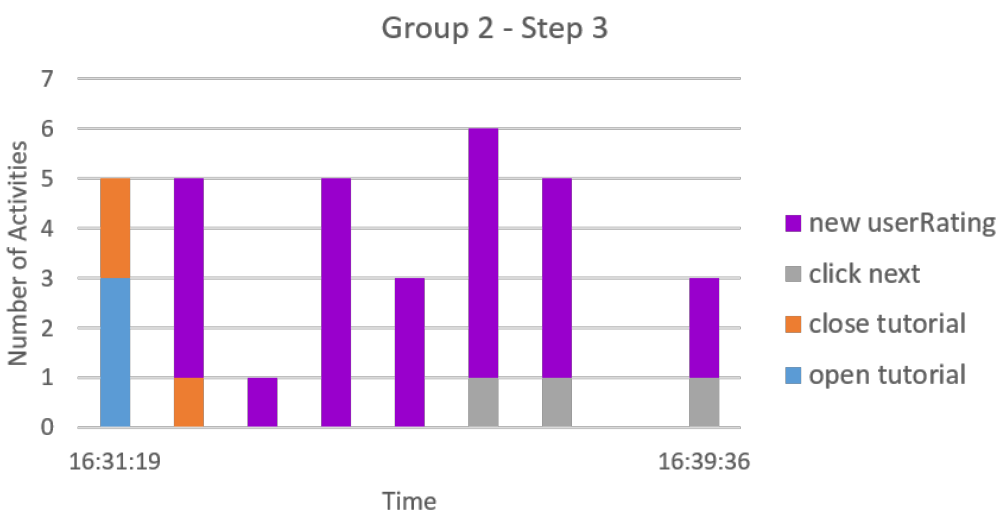


Figure C.2.: Timeline: User activities in step 3 (group 2)

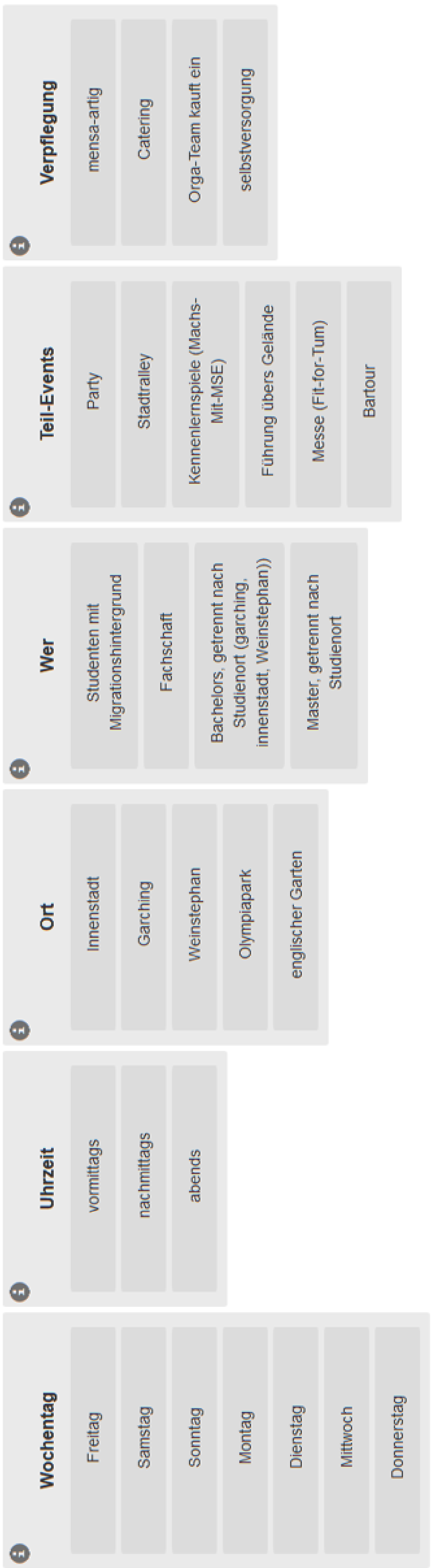


Figure C.3.: Final matrix of group 1

Figure C.4.: Final matrix of group 2

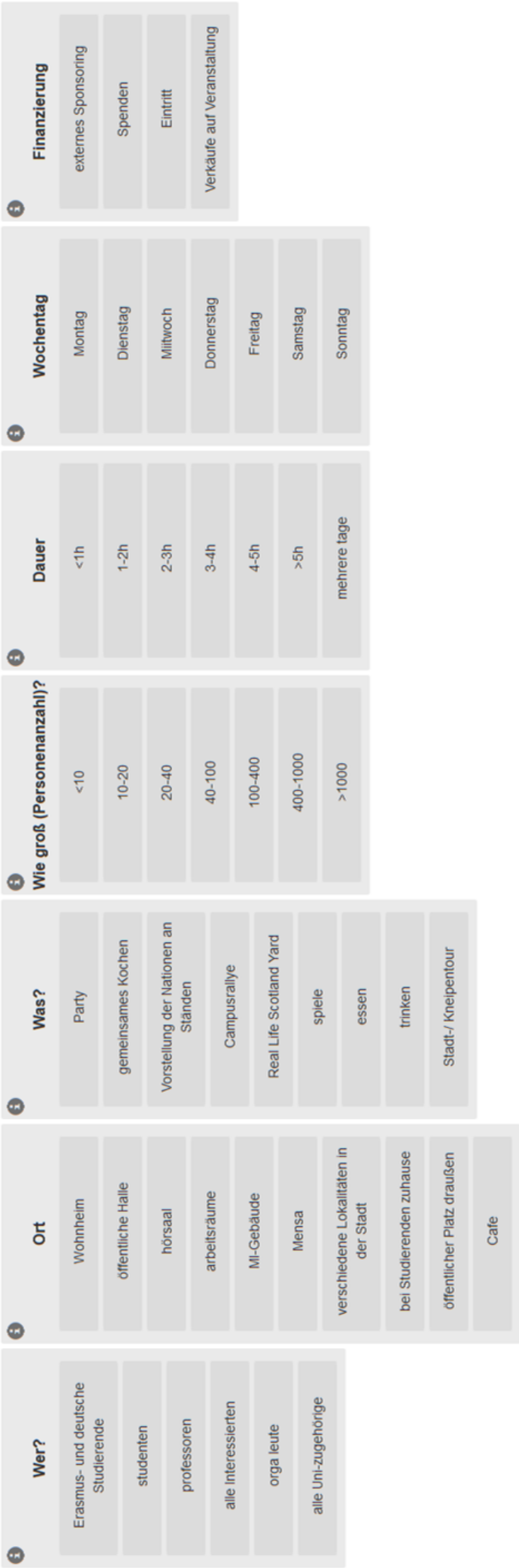


Figure C.5.: Final matrix of group 3

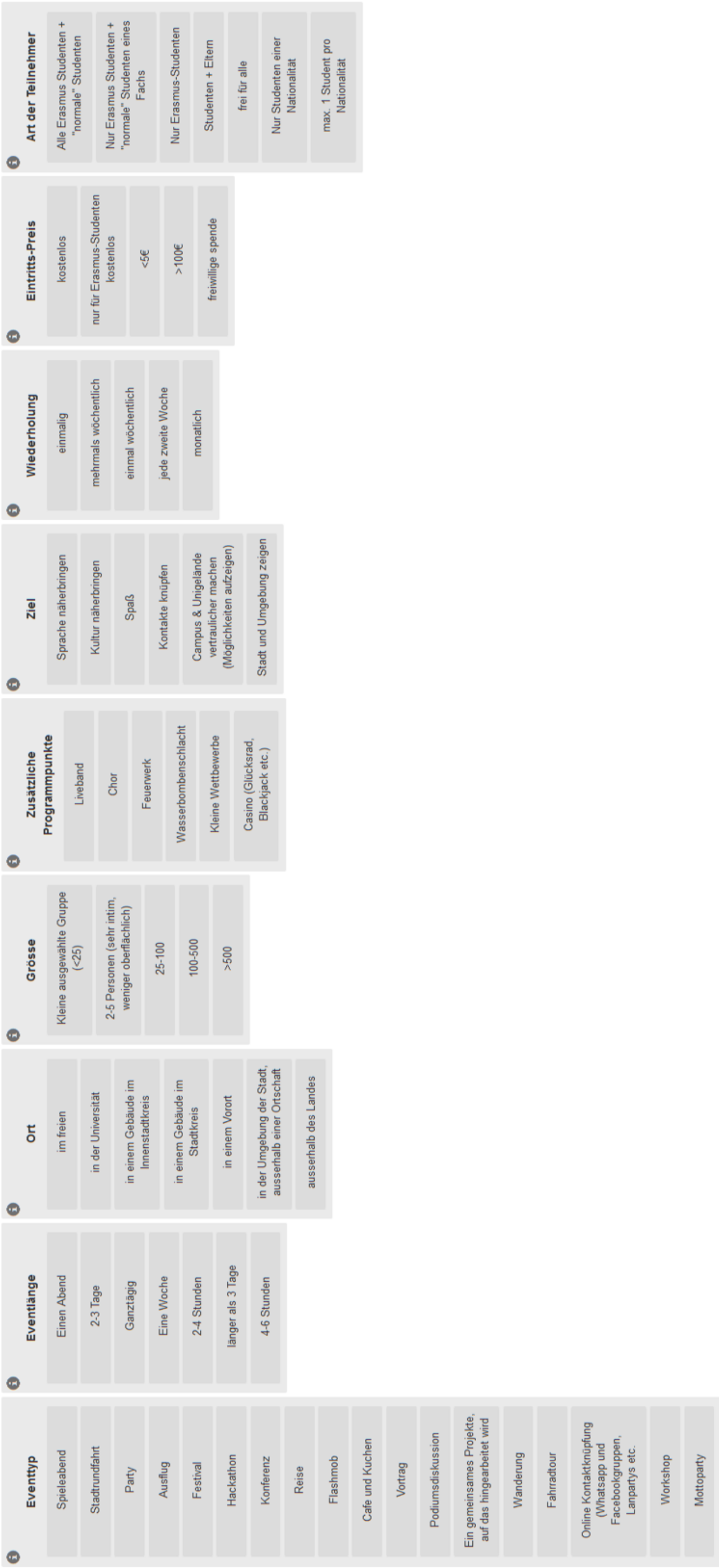
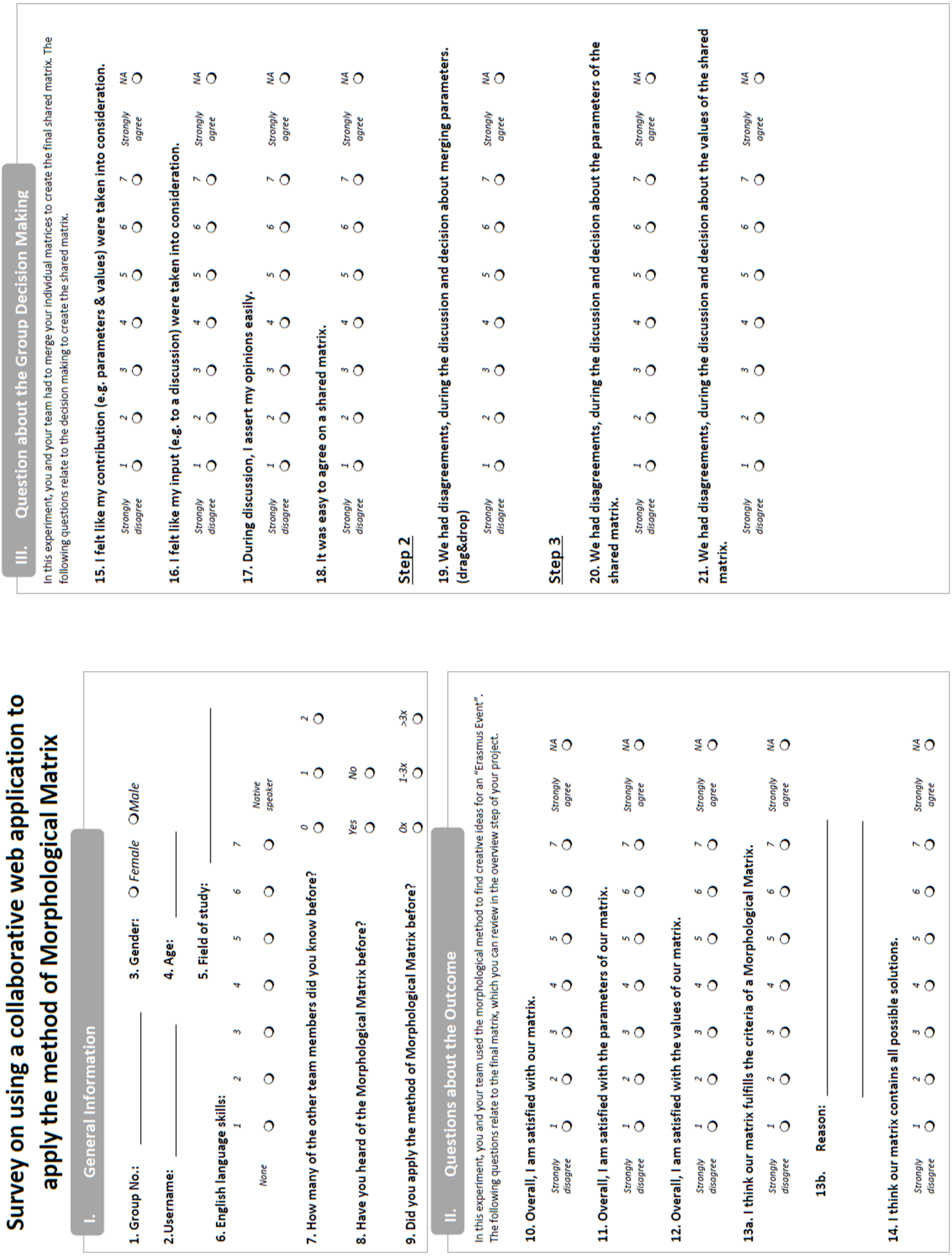


Figure C.6.: Final matrix of group 4



Survey on using a collaborative web application to apply the method of Morphological Matrix

I. General Information

1. Group No.: ______
2. Username: ______
3. Gender: ○ Female ○ Male
4. Age: ______
5. Field of study: ______
6. English language skills:
None 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Native speaker
7. How many of the other team members did you know before? 0 ○ 1 ○ 2 ○
8. Have you heard of the Morphological Matrix before? Yes ○ No ○
9. Did you apply the method of Morphological Matrix before? 0x ○ 1-3x ○ >3x ○

II. Questions about the Outcome

In this experiment, you and your team used the morphological method to find creative ideas for an "Erasmus Event". The following questions relate to the final matrix, which you can review in the overview step of your project.

10. Overall, I am satisfied with our matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

11. Overall, I am satisfied with the parameters of our matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

12. Overall, I am satisfied with the values of our matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

13a. I think our matrix fulfills the criteria of a Morphological Matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

13b. Reason: ______

14. I think our matrix contains all possible solutions.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

III. Question about the Group Decision Making

In this experiment, you and your team had to merge your individual matrices to create the final shared matrix. The following questions relate to the decision making to create the shared matrix.

15. I felt like my contribution (e.g. parameters & values) were taken into consideration.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

16. I felt like my input (e.g. to a discussion) were taken into consideration.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

17. During discussion, I assert my opinions easily.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

18. It was easy to agree on a shared matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

Step 2

19. We had disagreements, during the discussion and decision about merging parameters. (drag&drop)
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

Step 3

20. We had disagreements, during the discussion and decision about the parameters of the shared matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

21. We had disagreements, during the discussion and decision about the values of the shared matrix.
Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ Strongly agree NA ○

Figure C.7.: Evaluation questionnaire - page 1 (basic)

IV. Questions about the web application

In this experiment, you and your team used a web application, which guides you through the process of the morphological method. The following questions relate to the usage of that web application.

Usability Satisfaction

22. Overall, I am satisfied with the ease of creating a Morphological Matrix using the web application.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

23. Overall, I am satisfied with the amount of time it took to create a Morphological Matrix using the web application.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

24. Overall, I am satisfied with the support information (general tutorial, step tutorial, messages) when creating a Morphological Matrix using the web application.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

Usefulness

25. To create a Morph. Matrix, the web application is useful.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

26. To create a Morph. Matrix, the web application helps me to be more productive.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

27. The web application does everything I would expect it to do.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

In this experiment your team used the support of the web application to create a Morphological Matrix. It is also possible to use a whiteboard to create a Morph. Matrix collaboratively.

28. Imagine your team want to apply the morphological method again, which setting would you prefer?

❍ *Whiteboard/ paper & pen* ❍ *the web application* ❍ *I don't care*

29. From your point of view, list the most positive/negative aspects:

	Pro	*Contra*
Whiteboard /paper & pen		
Web application		

Ease of Learning

30. I learned to apply the method of Morph. Matrix quickly.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

31. I easily remember how to apply the method of Morph. Matrix.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

32. It is easy to learn to apply the method of Morph. Matrix.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

33. I quickly became skillful applying the method of Morph. Matrix.

Strongly disagree 1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍ *Strongly agree* NA ❍

34. What are your suggestions to improve usability satisfaction/usefulness/ease of learning?

V. Other

35. I used the following functionalities of the web application:

If not, why?

❍ *Drag & Drop* ______

❍ *Comments* ______

❍ *Adding description to a parameter* ______

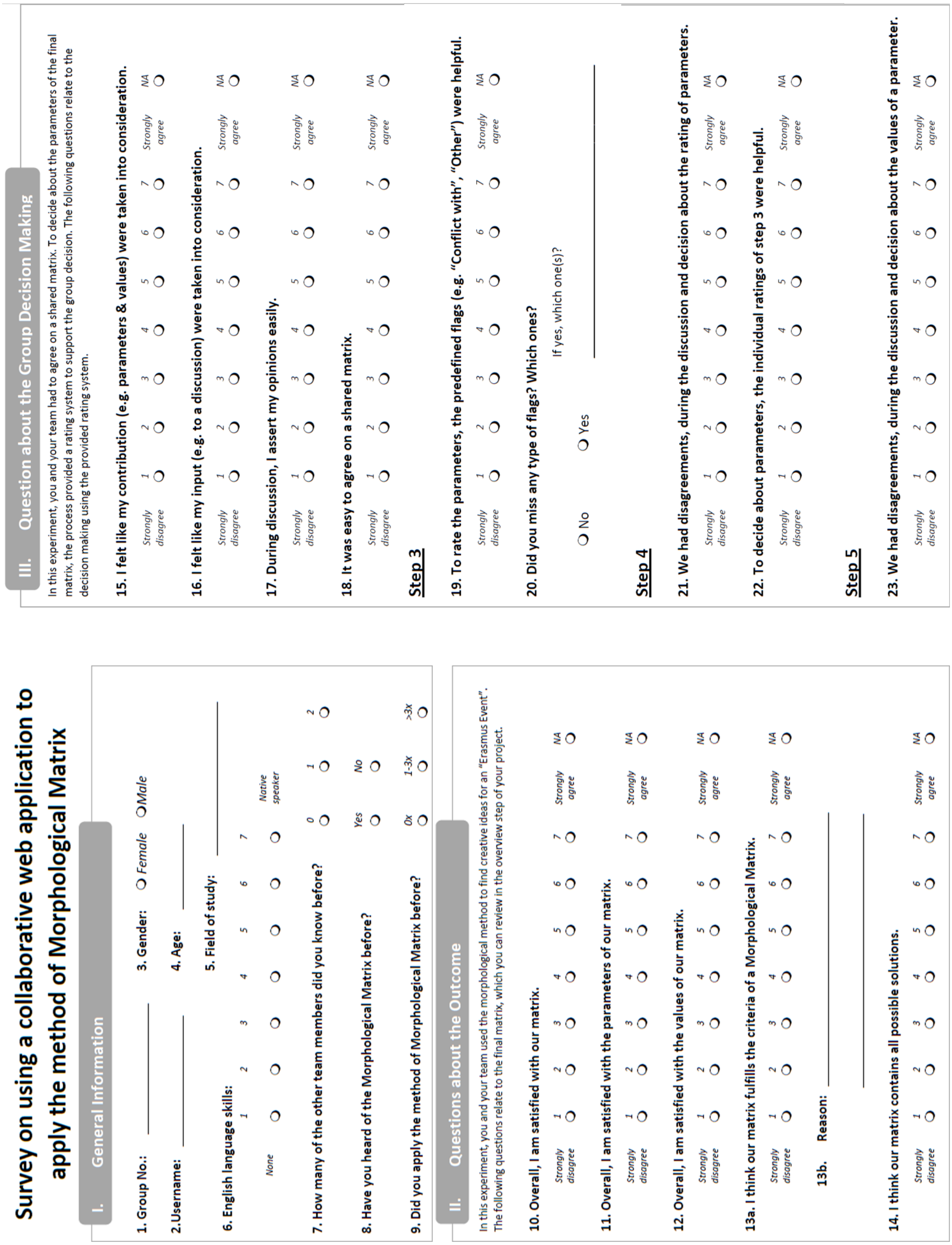
36. It was hard to complete the following step without talking with my team.

If yes, why?

❍ *Step 1* ______

37. What are your suggestions for additional functionalities of the web application?

Figure C.8.: Evaluation questionnaire - page 2 (basic)



Survey on using a collaborative web application to apply the method of Morphological Matrix

I. General Information

1. Group No.: ____________ 3. Gender: O Female O Male

2.Username: ____________ 4. Age: ____________

5. Field of study: ____________

6. English language skills: None 1 O 2 O 3 O 4 O 5 O 6 O 7 O Native speaker

7. How many of the other team members did you know before? 0 O 1 O 2 O

8. Have you heard of the Morphological Matrix before? Yes O No O

9. Did you apply the method of Morphological Matrix before? 0x O 1-3x O >3x O

II. Questions about the Outcome

In this experiment, you and your team used the morphological method to find creative ideas for an "Erasmus Event". The following questions relate to the final matrix, which you can review in the overview step of your project.

10. Overall, I am satisfied with our matrix.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

11. Overall, I am satisfied with the parameters of our matrix.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

12. Overall, I am satisfied with the values of our matrix.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

13a. I think our matrix fulfills the criteria of a Morphological Matrix.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

13b. Reason: ____________

14. I think our matrix contains all possible solutions.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

III. Question about the Group Decision Making

In this experiment, you and your team had to agree on a shared matrix. To decide about the parameters of the final matrix, the process provided a rating system to support the group decision. The following questions relate to the decision making using the provided rating system.

15. I felt like my contribution (e.g. parameters & values) were taken into consideration.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

16. I felt like my input (e.g. to a discussion) were taken into consideration.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

17. During discussion, I assert my opinions easily.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

18. It was easy to agree on a shared matrix.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

Step 3

19. To rate the parameters, the predefined flags (e.g. "Conflict with", "Other") were helpful.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

20. Did you miss any type of flags? Which ones?
O No O Yes If yes, which one(s)? ____________

Step 4

21. We had disagreements, during the discussion and decision about the rating of parameters.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

22. To decide about parameters, the individual ratings of step 3 were helpful.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

Step 5

23. We had disagreements, during the discussion and decision about the values of a parameter.
Strongly disagree 1 O 2 O 3 O 4 O 5 O 6 O 7 O Strongly agree NA O

Figure C.9.: Evaluation questionnaire - page 1 (extended)

IV. Questions about the web application

In this experiment, you and your team used a web application, which guides you through the process of the morphological method. The following questions relate to the usage of that web application.

Usability Satisfaction

24. Overall, I am satisfied with the ease of creating a Morphological Matrix using the web application.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

25. Overall, I am satisfied with the amount of time it took to create a Morphological Matrix using the web application.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

26. Overall, I am satisfied with the support information (general tutorial, step tutorial, messages) when creating a Morphological Matrix using the web application.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

Usefulness

27. To create a Morph. Matrix, the web application is useful.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

28. To create a Morph. Matrix, the web application helps me to be more productive.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

29. The web application does everything I would expect it to do.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

In this experiment your team used the support of the web application to create a Morphological Matrix. It is also possible to use a whiteboard to create a Morph. Matrix collaboratively.

30. Imagine your team want to apply the morphological method again, which setting would you prefer?

○ *Whiteboard/ paper & pen* ○ *the web application* ○ *I don't care*

31. From your point of view, list the most positive/negative aspects:

	Pro	Contra
Whiteboard /paper & pen		
Web application		

Ease of Learning

32. I learned to apply the method of Morph. Matrix quickly.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

33. I easily remember how to apply the method of Morph. Matrix.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

34. It is easy to learn to apply the method of Morph. Matrix.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

35. I quickly became skillful applying the method of Morph. Matrix.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ *Strongly agree* NA ○

36. What are your suggestions to improve usability satisfaction/usefulness/ease of learning?

V. Other

37. I used the following functionalities of the web application:

If not, why?

○ *Drag & Drop* ____________

○ *Comments* ____________

○ *Adding description to a parameter* ____________

38. It was hard to complete the following steps without talking with my team.

If yes, why?

○ *Step 1* ____________

○ *Step 3* ____________

39. What are your suggestions for additional functionalities of the web application?

Figure C.10.: Evaluation questionnaire - page 2 (extended)

Q1.	1	1	1
Q2.	**user1**	**user2**	**user3**
Q3.	M	F	F
Q4.	18	20	20
Q5.	Informatik	Ingenieurwissenschaften	Ingenieurwissenschaften
Q6.	5	7	6
Q7.	0	1	1
Q8.	N	N	N
Q9.	0x	0x	0x
Q10.	7	6	7
Q11.	6	7	7
Q12.	6	7	5
Q13.	7	6	7
Q13b.	*alles wichtige abgedeckt*	*enough parameters, but not too many / a lot of important aspects*	*Eckpunkte enthalten, nicht zu groß*
Q14.	7*	5	3
Q15.	7	7	7
Q16.	7	7	7
Q17.	6	7	5
Q18.	6	6	6
Q19.	4	6	4
Q20.	Y - *hängt zusammen mit, unwichtig*	N	Y - *unwichtig für den Anfang / zu spezifisch*
Q21.	5	5	3
Q22.	6	7	7
Q23.	7	5	3
Q24.	6	7	5
Q25.	7	7	4
Q26.	7	7	5
Q27.	6	6 *(local version?)*	6
Q28.	NA (*hab keine Erfahrungswerte*)	7	4
Q29.	5	6	5
Q30.	-	Web App	Whiteboard
Q31. - Pro1	-	*I personally can think better*	*höhere Kreativität, es schreibt nur einer -> Ordnung*
Q31. - Con1	*mangelnde Kombination von Werten (Parametern)*	*Erasing is more work*	*Platz, Papierverbrauch*
Q31. - Pro2	*unterstützt Brainstorming und Ergebnisfindung besser*	*easy to work with*	*wenig Platz, unlimitierte Fläche*
Q31. - Con2	*z.T. unwichtige Bedienung, Usability könnte besser sein*	*if server crashes, all information is lost*	*teilweise sehr unpersönlich*
Q32.	7	7	7
Q33.	7	7	7
Q34.	7	7	7
Q35.	7	6	6
Q36.	*Fenster per "Esc" schließbar, Kommentare evtl. schon bei moseover sichtbar, z.T. lange Wege von Klick zu Klick, Sobald die Sektionen den Bildschirm rechts verlassen haben wird's unübersichtlich*	*To move it to a local version for companies etc. to use it in their ethernet*	*Bei denTeilen, die in der Gruppe diskutiert werden, sollte nur einer die Parameter verändern können*
Q37.			
D&D	used	used	used
Comment	used	used	not used ("*erschien mir unwichtig*")
Descrip.	used	used	not used ("*erschien mir unwichtig*")
Q38.	-	-	-
Q39.	*Telefonfunktion, damit man nicht in einem Raum sitzen muss*	*Move parameters within the matrix to have similar ones aligned to each other*	-
*	*logisch gesehen ist immer noch eine Veränderung möglich, aber die meisten Lösungen sind abgedeckt*		

Table C.1.: Questionnaire results - group 1

Q1.	2	2	2
Q2.	**user4**	**user5**	**user6**
Q3.	M	M	M
Q4.	21	21	20
Q5.	Wirtschaftsinformatik	TUM-BWL	TUM-BWL
Q6.	6	6	7
Q7.	0	1	1
Q8.	N	N	N
Q9.	0x	0x	0x
Q10.	6	6	6
Q11.	6	6	6
Q12.	7	5	6
Q13.	7	7	6
Q13b.	*different parameters, values*	-	-
Q14.	5	2	6
Q15.	7	7	6
Q16.	7	7	6
Q17.	5	7	5
Q18.	2	7	4
Q19.	5	6	4
Q20.	Y - *depends on*	N	N
Q21.	6	7	6
Q22.	7	7	3
Q23.	7	7	6
Q24.	7	7	5
Q25.	5	7	4
Q26.	7	7	4
Q27.	7	7	6
Q28.	7	6	6
Q29.	7	6	5
Q30.	Web app	Web app	Web app
Q31. - Pro1	*Kein Raster vorgegeben*		*individuel*
Q31. - Con1	*Änderungen schwierig*	*zeitaufwändig*	
Q31. - Pro2	*Änderungen einfach*	*jede Stimme hat Gewicht*	*Hilfestellung*
Q31. - Con2		*wird in größeren Gruppen sehr zeitintensiv*	*vorgegeben*
Q32.	7	7	7
Q33.	7	7	7
Q34.	7	7	7
Q35.	6	7	6
Q36.	*See progress of others*	-	-
Q37.			
D&D	used	used	used
Comment	used	used	used
Descrip.	used	not used: *selbst erklärende Parameter*	not used: -
Q38.	Step 1: *see progress*		Step3: *(no reason)*
Q39.	-	*in größeren Gruppen vlt. Eine Evaluierungsrunde nach 1. Ansicht*	-

Table C.2.: Questionnaire results - group 2

Q1.	3	3	3
Q2.	**user7**	**user8**	**user9**
Q3.	F	M	F
Q4.	19	18	20
Q5.	games engineering	games engineering	mathematics
Q6.	5	5	4
Q7.	1	1	0
Q8.	N	N	N
Q9.	0x	0x	0x
Q10.	6	5	6
Q11.	7	5	6
Q12.	5	6	7
Q13.	5	6	7
Q13b.	*mögliche Abhängigkeiten verschiedener values*	*7 Parameter, die nicht voneinander abhängen*	*Deckt alle nötligen Aspekte ab, hat viele verschiedene Kombi-möglichkeiten, keine Überschneidung der values*
Q14.	5	2	3
Q15.	6	7	7
Q16.	7	5	7
Q17.	6	7	5
Q18.	7	6	6
Q19.	2	2	3
Q20.	3	3	2
Q21.	2	2	4
Q24.	7	5	3
Q25.	7	6	6
Q26.	5	6	6
Q27.	6	7	4
Q28.	Web app	Web app	Web app
Q29. - Pro1	*gute kombination (Organisation der Teilnehmer nötig)*	*Kommunikation*	*mehr direkte Diskussion, Ideen gemeinsam entwickeln*
Q29. - Con1	*manchmal unleserlich*	*Übersichtlichkeit geht schnell verloren*	*unkonventionelle Vorschläge gehen evtl. verloren*
Q29. - Pro2	*gut sortiert, aktualisiert sofort, zeiterspranis*	*Übersichtlichkeit, Brainstorming kann zu anderem Zeitpunkt fortgesetzt werden*	*kreative Ideen entstehen*
Q29. - Con2	*bugs, wenig kommunikation*	*weniger Kommunikation Ablenkung möglich*	*bei zu wenig Kommunikation gehen gute Vorschläge evtl. verloren*
Q30.	7	5	5
Q31.	7	7	6
Q32.	7	5	5
Q33.	7	4	4
Q34.	*Entertaste zum bestätigen und beim Hinzufügen von Kommentaren*	*Evtl. Beschreibung des aktuellen Schritts dauerhaft einblenden*	*Anzeige, was passiert wenn Knopf gedrückt wird beim drüber fahren*
Q35.			
D&D	used	used	used
Comment	not used: *nicht notwendig für das umzusetzende*	not used: *Wie die Kommentare nicht direkt sichtbar sind*	not used: *persönliche Aussprache angenehmer*
Descrip.	used	not used: *Wie die Kommentare nicht direkt sichtbar sind*	not used: *persönliche Aussprache angenehmer*
Q36.	-	-	-
Q37.	*Ordnerverwaltug: z.B. sowas wie "eigene Projekte" -> z.B. Arbeitsaccount für mehrere Teammitglieder*	*Hand-Symbol für Drag&Drop*	*Diskussionsforen zu jedem Parameter & Value, falls Team nicht innerhalb eines Raums ist*
*	*seitwärts scrollen während dem zusammenführen der Kategorien wäre sinnvoll*		

Table C.3.: Questionnaire results - group 3

Q1.	4	4	4
Q2.	**user10**	**user11**	**user12**
Q3.	M	M	M
Q4.	18	18	22
Q5.	Winfo	Winfo	Computer science
Q6.	6	5	5
Q7.	1	1	0
Q8.	N	N	N
Q9.	0x	0x	0x
Q10.	6	5	5
Q11.	6	6	6
Q12.	5	7	5
Q13.	7	6	4
Q13b.	*new ideas*	*we've got way to much values*	*too many values*
Q14.	5	4	4
Q10.	6	5	5
Q11.	6	6	6
Q12.	5	7	5
Q13.	7	6	4
Q13b.	*new ideas*	*we've got way to much values*	*too many values*
Q14.	5	4	4
Q22.	5	7	6
Q23.	6	7	7
Q24.	6	6	6
Q25.	7	7	7
Q26.	NA	6	7
Q27.	6	4	5
Q28.	Web app	Web app	Web app
Q29. - Pro1	*without a computer*	*probably better for presentations*	-
Q29. - Con1	*not online/in the cloud, one-person-work*	*waste of paper(and pens)*	*hard to work on it paralell*
Q29. - Pro2	*shared work, always available*	*Everyone can easily take paut (?) in it*	*distributed, easy collaborative working*
Q29. - Con2	*you're not able to see who changed what, pc needed, everyone of the team has to use it*	*Less interactive*	-
Q30.	7	7	6
Q31.	7	7	6
Q32.	7	7	6
Q33.	7	6	4
D&D	used	used	used
Comment	used	used	not used: *could talk with team*
Descrip.	used	used	not used: *everyone could ask if something wasn't clear*
Q36.	-	-	-
Q37.	*sort parameters, colors for parameters, invite/share teammembers, export results to .jpg/.pdf*	*random creations out of the values*	-
*		*step 1: wasting time, 'cause everybody writes similar parameters*	

Table C.4.: Questionnaire results - group 4

Colophon

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